A

MANUAL OF PHYSIOLOGY.

By the same Author.

THE MICROSCOPE AND ITS REVELATIONS,

WITH TEN PLATES AND NEARLY FOUR HUNDRED WOOD ENGRAVINGS.

Third Edition. Foolscap 8vo., cloth, 12*s.* 6*d.*

PRINCIPLES OF HUMAN PHYSIOLOGY,

WITH MORE THAN TWO HUNDRED ILLUSTRATIONS ON STEEL AND WOOD.

Sixth Edition. 8vo., cloth, 26*s.*

A MANUAL

OF

PHYSIOLOGY,

INCLUDING

PHYSIOLOGICAL ANATOMY.

BY

WILLIAM B. CARPENTER, M.D.

F.R.S., F.L.S., F.G.S.,

REGISTRAR OF THE UNIVERSITY OF LONDON.

FOURTH EDITION,

WITH TWO PLATES AND TWO HUNDRED AND FIFTY WOOD ENGRAVINGS.

LONDON:

JOHN CHURCHILL & SONS, NEW BURLINGTON STREET.

M DCCC LXV.

LONDON:
PRINTED BY WERTHEIMER AND CO.,
CIRCUS PLACE, FINSBURY CIRCUS.

PREFACE.

In the original preparation of this Manual, it was the special aim of the Author "to convey to the Student as clear an idea as possible of those Principles of Physiology which are based on the broadest and most satisfactory foundation; and to point out the mode in which these principles are to be applied to the interpretation of the phenomena presented by the living actions of the Human body." In his preference for this plan over one which should fix the attention of the reader upon particular facts rather than upon general doctrines, and should lead him to dwell rather upon the details of the Physiology of Man, than upon those great truths which are brought into view by a comprehensive survey of the Organized Creation, the Author has found himself justified not merely by his own subsequent experience as a Teacher, but even more by the history of Physiological Science during the last twenty years. For whilst the industry of observers and experimentalists has brought together a vast body of new *facts*, and has subjected those previously accepted to a new and rigid scrutiny, it has more and more generally come to be recognized that the chief value of facts consists, in Physiology as in other Sciences, in

the basis they afford for the establishment of *laws*, and that no basis can here suffice which does not extend over the whole domain of Life.

In the preparation of the present Edition, therefore, the Author has endeavoured at the same time to carry out his original design with greater completeness, and to introduce into its details such additions and modifications as the progress of Physiological research should seem to require. In pursuance of the first of these objects, he has devoted a special Chapter to the Chemical Components of the Animal body; he has remodelled and extended the Chapter on the Primary Tissues, so as to make it include as much Histology as he thinks it essential for the Student to learn; and he has rewritten in greater detail the section on Embryonic Development, so as to bring its scale into better accordance with that on which other subjects are treated. With the view of attaining the second he has carefully revised every portion of the Treatise, and has spared no pains in the addition or substitution of more full and exact information, wherever he found occasion for such improvement.

To one subject in particular he desires here to draw attention, as he believes that the mode in which he has treated it will serve as an apposite exemplification of the advantage of discussing Physiological questions in their *most general* as well as in their *special* bearing. He refers to the modification of what is commonly called the 'cell-doctrine,' which seems to him to be now rendered necessary by the concurrence of the results obtained by several observers labouring independently of each other in different fields of research. For it now appears to be con-

clusively established that the Cell, with its membranous wall, nucleus, and contents, is no longer to be taken as the primitive type of organization ; but that the nearest approach to this type is to be found in the segment of 'protoplasmic substance' or 'sarcode' which forms the entire body of the lowest Animals :*—and further, that the portion of the fabric of even the highest Animals which is most actively concerned in Nutrition, is a protoplasmic substance diffused through every part, its segments being sometimes in continuous connection with each other, sometimes isolated by the formation of 'cell-walls' around them. Hence the study of the life-history of the *Rhizopoda*, which their ordinarily minute size and transparence renders comparatively easy, comes to throw a most unexpected light upon the phenomena which occur in the innermost *penetralia* of the complex organization of Man. The Author considers it due to his friend Prof. Beale to state that he regards his labours as having contributed more than those of any other Histologist to this result ; but feels it right at the same time to notice his dissent from Prof. Beale's views on one important point, viz., his denial of vital activity to the 'formed material' of the Tissues produced by the agency of the 'germinal matter' (p. 440 *note*).

Not only has the Text of the present Edition been augmented by nearly a hundred pages, but the number of

* Recent Paleontological enquiry has shown that this Rhizopod type was represented in the earlier periods of the Earth's history, not by the comparatively insignificant *Foraminifera* of later epochs, but by massive Coral-like structures, which had a large share in the formation of the oldest Calcareous rocks. See the account of *Eozoon Canadense* in Quart. Journ. of Geol. Soc., Feb. 1865.

Wood-Engravings has been increased from 180 to 250. For several of the additional Illustrations in Chapter IV. the Author is indebted to the kindness of Prof. Beale; and those introduced in Chapter XII. are for the most part taken from the Treatise on Human Physiology by Dr. Dalton of New York, to which work the Author has great satisfaction in referring such of his readers as desire a fuller account of the development of the Embryo than the limits of this Manual allow of his giving, while he gladly records his own obligations to it for valuable information not only on this but on several other topics.

University of London,
March 1, 1865.

TABLE OF CONTENTS.

BOOK I.

GENERAL PHYSIOLOGY.

BOOK II.

SPECIAL PHYSIOLOGY.

LIST OF WOOD ENGRAVINGS.

EXPLANATION OF PLATE I.

The Figures in this Plate represent the Cells floating in the various animal fluids; and they are all, with the exception of Figs. 4 and 5, copied from the representations given by M. Donné in his "Atlas de l'Anatomie Microscopique." These representations are transcripts of Daguerreotype pictures, obtained from the objects by a solar microscope, with a magnifying power of 400 diameters.

Fig 1. Red Corpuscles of Human Blood, viewed by their flattened surfaces (§ 216).

Fig. 2. Red Corpuscles of Human Blood, adherent by their flattened surfaces, so as to form rolls; — at *a*, the entire surfaces are adherent; at *b*, their surfaces adhere only in part (§ 218).

Fig. 3. Red Corpuscles of Human Blood, exhibiting the granulated appearance which they frequently present, a short time after being withdrawn from the vessels (§ 216).

Fig. 4. Colourless Corpuscles of Human Blood (§ 214).

Fig. 5. The same, enlarged by imbibition of water.

Fig. 6. Red Corpuscles of Frog's Blood (§ 216).

Fig. 7. The same, treated with dilute acetic acid; the first effect of which is to render the nucleus more distinct, as at *b*; after which the investing substance becomes more transparent, and its solution commences, as at *a*.

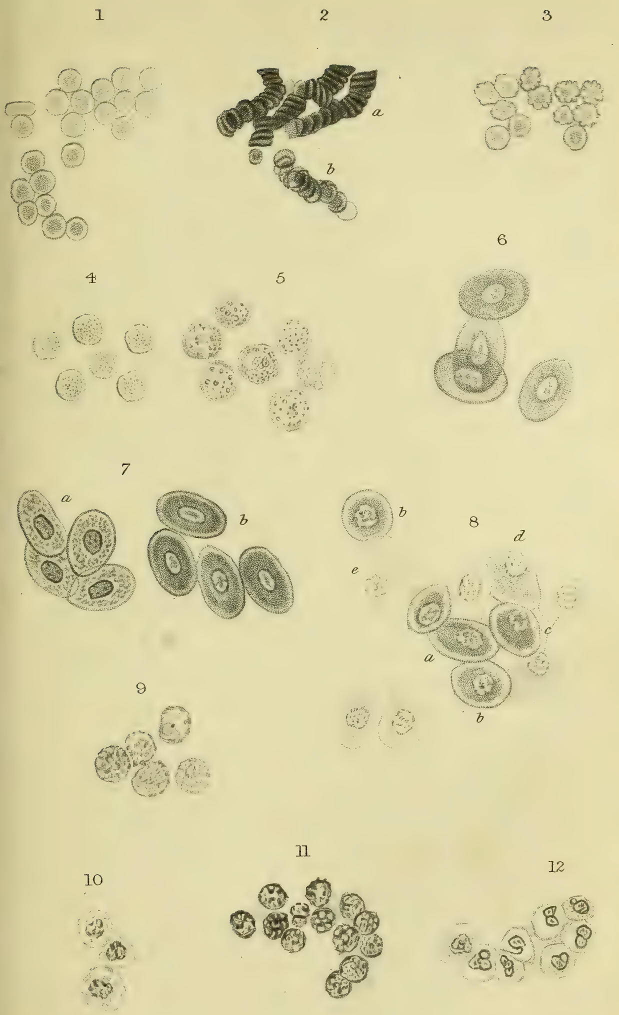
Fig. 8. The same, treated with water; at *a* is seen a corpuscle nearly unaltered, except in having the nucleus more sharply defined; at *b*, others which have become more spherical, under the more prolonged action of water; at *c*, the nucleus is quitting the centre and approaching the circumference of the disk; at *d* it is almost freeing itself from the envelope; and at *e* it has completely escaped (§ 217).

Fig. 9. Globules of Mucus, newly secreted (§ 238).

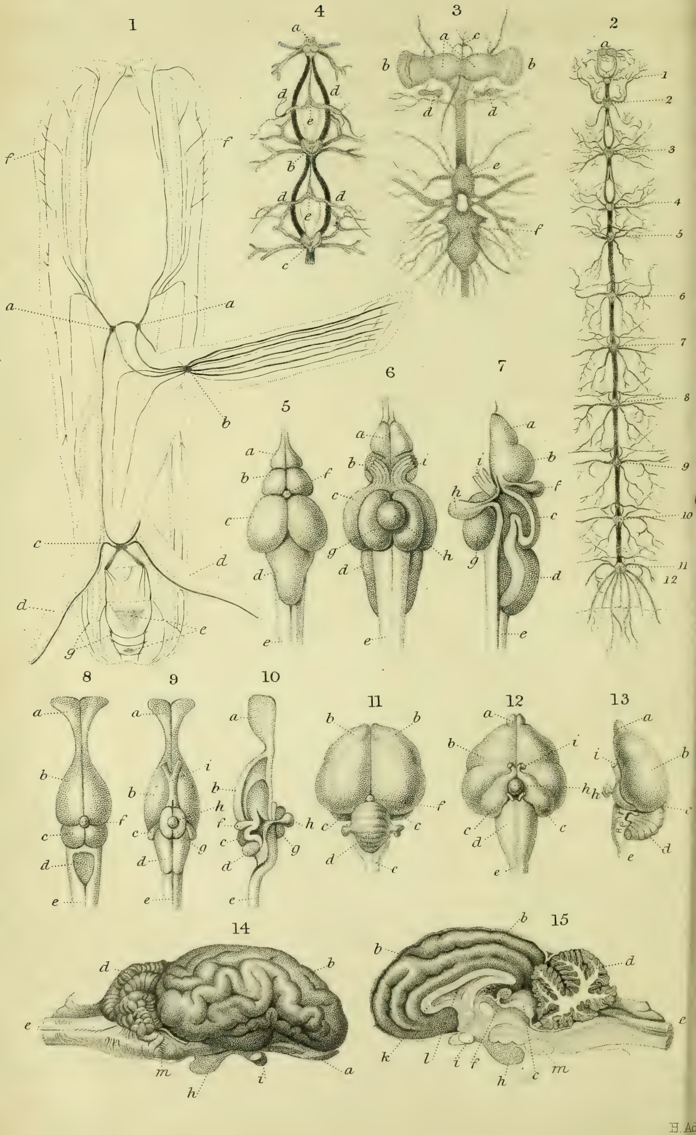
Fig. 10. The same, acted-on by acetic acid.

Fig. 11. Globules of Pus, from a phlegmonous abscess.

Fig. 12. The same, acted-on by acetic acid.



J. Adlard sc.


1
4
3
2
5
6
7
8
9
10
11
12
13
14
15
H. Ad

EXPLANATION OF PLATE II.

The Figures in this Plate represent the principal forms of the Nervous Centres in different classes of animals. The first is copied from a Memoir by M. Blanchard; the 2nd, 3rd, and 4th, from Mr. Newport's delineations; the 5th to the 13th, from the work of M. Guillot on the Comparative Anatomy of the Encephalon in the different classes of Vertebrata; and the last two from the work of M. Leuret on the same subject.

Fig. 1. Nervous System of *Solen; a, a*, cephalic ganglia, connected together by a transverse band passing over the Œsophagus, and connected with the other ganglia by cords of communication; *b*, pedal ganglion, the branches of which are distributed to the powerful muscular foot; *c*, branchial ganglion, the branches of which proceed to the gills *d, d*, the siphons *e, e*, and other parts. On some of these branches, minute ganglia are seen; as also at *f, f*, on the trunks that pass forwards from the cephalic ganglia (§ 852).

Fig. 2. Nervous System of the *Larva* of *Sphinx ligustri; a*, cephalic ganglia; 1—12, ganglia of the ventral cord (§ 856).

Fig. 3. Anterior portion of the Nervous System of the *Imago* of *Sphinx ligustri; a*, cephalic ganglia; *b, b*, eyes; *c*, anterior median ganglion, and *d, d*, posterior lateral ganglia of stomato-gastric system; *e, f*, large ganglionic masses in the thorax, giving origin to the nerves of the legs and wings (§§ 861, 863).

Fig. 4. Thoracic portion of the Nervous System of the *Pupa* of *Sphinx ligustri; a, b, c*, three ganglia of the ventral cord; *d, d*, their connecting trunks; *e, e*, respiratory ganglia (§ 862).

Fig. 5. Brain of *Perch*, seen from above (§ 869).
Fig. 6. The same, as seen from below.
Fig. 7. Interior of the same, as displayed by a vertical section.

The following references are common to the three preceding, and to the succeeding figures:—

a, *a*, Olfactory lobes or ganglia.
b, *b*, Cerebral ganglia or Hemispheres.
c, *c*, Optic lobes.
d, Cerebellum.
e, Spinal cord.
f, Pineal gland.
g, Lobi inferiores (their precise character not determined).
h, Pituitary body.
i, Optic Nerves.

Fig. 8. Brain of the *Common Lizard*, seen from above (§ 871).
Fig. 9. The same, as seen from below.
Fig. 10. The same, as displayed by a vertical section.
Fig. 11. Brain of the *Common Goose*, seen from above (§ 872).
Fig. 12. The same, as seen from below.
Fig. 13. The same, as displayed by a vertical section.
Fig. 14. Brain of the *Sheep*, viewed sideways (§ 873).
Fig. 15. The same, as displayed by a vertical section.

In addition to the parts indicated by the preceding references, we have here to notice;—*k*, the corpus callosum; *l*, the septum lucidum; and *m*, the Pons Varolii.

BOOK I.

GENERAL PHYSIOLOGY.

CHAPTER I.

ON THE NATURE AND OBJECTS OF THE SCIENCE OF PHYSIOLOGY.

1. The general distribution of the objects presented to us by external Nature, into three kingdoms—the Animal, the Vegetable, and the Mineral—is familiar to every one; and not less familiar is the general distinction between living bodies, and inert matter. True it is, that we cannot always clearly assign the limits which separate these distinct classes of objects. Even the professed Naturalist is constantly subject to perplexity, as to the exact boundary between the Animal and the Vegetable kingdoms; and the distinction between Animal and Vegetable structures on the one hand, and Mineral masses on the other,—or between living bodies, and aggregations of inert matter,—is by no means so obvious in every case, as to be at once perceptible to the unscientific observer. Thus, a mass of Coral, if its growing portion be kept out of view, or a solid Nullipore attached to the surface of a rock, might be easily confounded with the mineral masses to which either bears so close a resemblance; and a minute examination might be required to detect the difference. Nevertheless, a well-marked distinction does exist between the *organized* structures of Plants and Animals, and the *inorganic* aggregations of Mineral matter; as well as between the condition of a *living* being, whether Animal or Plant, and that of *dead* or *inert* Mineral bodies. It is upon these distinctions, which are usually obvious enough, that the sciences of Anatomy and Physiology are founded; these sciences taking cognizance,—the former, of those structures which are termed *organized*,—and the latter, of the actions which are peculiar to those structures, and which are distinguished by the term *vital*. It will be desirable to consider, in a somewhat systematic order, the principal ideas which we attach to these terms; as we shall be thus led most directly to the distinct comprehension of the nature and objects of Physiological science.

1. *General Characters of Organized Structures.*

2. Organized structures are characterized, in the first place, by the peculiarities of their *form*.—Wherever a definite form is exhibited by Mineral substances, it is bounded by straight lines and angles, and is the effect of the process termed *crystallization.* This process results from the tendency which evidently exists in particles of matter, especially when passing gradually from the fluid to the solid state, to arrange themselves in a regular and conformable manner in regard to one another. There is, perhaps, no solid Inorganic element or combination which is not capable of assuming such a form, if placed in circumstances adapted to the manifestation of this tendency among its particles; but if these conditions should be wanting, so that simple cohesive attraction is exercised in bringing them together, without any general control over their direction, an indefinite or shapeless figure is the result.—Neither of these conditions finds a parallel in the Organized creation. From the highest to the lowest, we find the shape presenting a determinate character for each *species* or *race*, with a certain limited amount of variation amongst *individuals;* and this shape is such, that, instead of being circumscribed within plane surfaces, straight lines, and angles, organized bodies are bounded by convex surfaces, and present rounded outlines. We may usually gather, moreover, from their external form, that they are composed of a number of dissimilar parts, or *organs;* which are combined together in the one individual body, and are characteristic of it. Thus in the Vertebrated or Articulated animal, we at once distinguish the head and extremities from the trunk which constitutes the principal mass; and where there exist no external organs of such distinctness, as in some Mollusks, the rounded character of the general form is sufficiently characteristic. The very simplest grades of animal and vegetable life present themselves under a shape which approaches more or less closely to the globular. It is among the lower tribes of both kingdoms that we find the greatest tendency to irregular departures from the typical form of the species; and thus is presented an approach, on the one hand, to that indefiniteness which is characteristic of non-crystalline mineral masses; and, on the other, to that variety of crystalline forms which the same mineral body may present rccording to the circumstances which influence its crystallization.

3. With regard to *size*, again, nearly the same remarks apply. The magnitude of Inorganic masses is entirely indeterminate being altogether dependent upon the number of particles which can be brought together to constitute them. On the other hand the size of Organized structures is restrained, like their form within tolerably definite limits, which may nevertheless vary to

certain extent among the individuals of the same species. These limits are least obvious in Vegetables, and in the lower classes of Animals. A forest-tree may go on extending itself to an almost indefinite extent; certain species of sea-weed attain a length of many hundred feet, and their growth does not appear to be restrained by any limit; and the same may be said of those enormous masses of coral, which compose so many islands and reefs in the Polynesian Archipelago, or of which the *débris* seem to have constituted most of the calcareous rocks of ancient formation. But in these cases, the increase is produced by the multiplication of similar parts, which, when once completely evolved, have but little dependence one upon another, and might be almost considered as distinct individuals. Thus, each bud of a tree, if placed under favourable circumstances, can maintain its life by itself, and can perform all the actions proper to the species. Each polype of the coral mass, in like manner, at first produced by a process of budding from the original stock, comes in time to be completely independent both of it and of those with which it is associated. And in the sea-weed, each portion of the frond is an almost precise repetition of every other, and grows for and by itself; neither receiving from, nor communicating to, any other part, the materials of its organic structure. Thus among Plants and the lower Animals, we find an indefiniteness in point of size, depending upon the tendency to multiplication of similar parts, which has been designated as *vegetative* repetition.

4. It is, however, in the internal arrangement or aggregation of he particles of which Organized structures and Inorganic masses re respectively composed, that we find the difference between the wo most strongly marked.—Every particle of a Mineral body (in vhich there has not been a *mixture* of ingredients) exhibits the ame properties as those possessed by the whole; so that the hemist, in experimenting with any substance, cares not, except s a matter of convenience merely, whether a grain or a ton be he subject of his researches. The minutest atom of carbonate of ime, for instance, has all the properties of a crystal of this subtance, were it as large as a mountain. Hence we are to regard a nineral body as made up of an indefinite number of constituent articles, similar to it and to each other in properties, and having no urther relation among themselves than that which they derive from heir juxta-position. *Each particle*, then, may be considered as ossessing a *separate individuality;* since we can predicate of its roperties all that can be said of the largest mass.—The organized tructure, on the other hand, receives its designation from being nade up of a number of distinct parts or *organs*, each of which has a exture and consistence peculiar to itself; and it derives its character rom the whole of these collectively. Every one of them, as we hall hereafter see, is the instrument of a certain action or *function*,

which it performs under certain conditions; and the concurrence of all these actions is required for the maintenance of the structure in its normal or regular state, and for the prevention or the reparation of those changes, which Chemical and Physical forces would otherwise speedily produce in it. Hence there is a relation of *mutual dependence* among the parts of an Organized structure, which is quite distinct from that of mere proximity. The perfect Plant, which has roots, stem, leaves, and flowers, is an example of an organized structure in which the relation of the different parts to the integrity of the whole is sufficiently obvious; since, when entirely deprived of either set of these organs, the race must perish, unless the plant have within itself the power of reproducing them.

5. It is not only in Zoophytes and other *aggregate* Animals, that we notice the tendency to 'vegetative repetition;' for it may be observed in many animals which cannot be divided without the destruction of their lives,—especially among the Radiated and the lower Articulated tribes. Where such a repetition exists, *some* of the organs may be removed without permanent injury to the structure; their function being performed by those that remain. Thus, it is not uncommon to meet with specimens of the common five-rayed Starfish, in which not only one or two of the 'arms,' but even three or four, have been lost without the destruction of the animal's life; and this is the more remarkable, as the arms are not simply members for locomotion or prehension, but are really divisions of the body containing prolongations of the stomach. In the bodies of the higher animals, however, where there are few or no such repetitions (save in the two lateral halves of the body), and where there is consequently a greater diversity in character and function between the different organs, the mutual dependence of their actions upon one another is much greater, and the loss of a single part is much more likely to endanger the existence of the whole. Such structures are said to be more *highly-organized* than those of the lower classes; not because the whole number of parts is greater, for it is frequently much less; but because the number of *dissimilar* parts, and the consequent adaptation to a *variety* of purposes, is much greater,—the principle of division of labour,' in fact, being carried much further, a much greater variety of objects being attained, and a much higher perfection in the accomplishment of them being thus provided for.

6. Keeping in view, then, what has just been stated in regard to the divisibility of a Tree or a Zoophyte into a number of parts, each capable of maintaining its own existence, we may trace a certain gradation from the condition of the Mineral body to that of the highest Animal, in regard to the character in question. Using the term individuality as a convenient expression for the capacity for independent existence, it may be said that the *indi-*

viduality of a Mineral substance resides in each molecule; that of a Plant or Zoophyte, in each complete member; and that of one of the higher Animals, in the sum of all the organs.—The distinction is much greater, however, between the lowest Organized fabric and *any* Mineral body, than it is between the highest and the lowest organized structures: for, as we shall hereafter see, the highest and most complicated may be regarded as made-up of an assemblage of parts corresponding to the lowest and simplest, the structure and actions of which have been so modified as to render them mutually dependent; but which yet retain a power of independent activity, that enables them to continue performing their functions when separated from the mass, so long as the requisite conditions are supplied.

7. Between the very simplest Organized fabric, and every form of Mineral matter, there is a marked difference in regard to *intimate structure* and *consistence.* Inorganic substances can scarcely be regarded as possessing a structure; since (if there be no admixture of components) they are uniform and *homogeneous* throughout, whether existing in the solid, the liquid, or the gaseous form; being composed of similar particles, held-together by attractions which affect all alike. Far different is the character of Organized structures; for in the minutest parts of these may be detected a *heterogeneous* composition,—a mixture of solid and fluid elements, which are so intimately combined and arranged, as to impart such peculiarities to the tissues, even in regard to their physical properties, as we never encounter amongst Mineral bodies. In the latter, *solidity* or *hardness* may be looked-upon as the characteristic condition; whilst in Organized structures, *softness* (resulting from the large proportion of fluid components) may be considered the distinctive quality, being most obvious in the parts that are most actively concerned in vital operations. This softness is evidently connected with the roundness of form characteristic of Organized fabrics, which is most evident when the tissues contain the greatest proportion of fluid; whilst the plane surfaces and angular contours of Mineral bodies are evidently due to the mode in which the solid particles are aggregated-together, without any intervening spaces.

8. The greatest solidity exhibited by Organized fabrics, is found where it is desired to impart to them the simple physical property of *resistance;* and this is attained by the deposition of solid particles, often of a mineral character, in tissues that were originally soft and yielding. It is in this manner that the almost jelly-like substance, in which all the organs of animals originate, becomes condensed into cartilage, and that the cartilage is afterwards replaced by bone; it is in the same manner, also, that the stones of fruit, and the heart-wood of timber-trees, are formed out of softer tissues. But, as we shall hereafter see, this kind of

conversion, whilst it renders the tissue more solid and durable, cuts it off from active participation in the vital operations; and thus reduces it to a state much more nearly analogous to that of mineral bodies. This resemblance is rendered more close by the fact, that the earthy deposits frequently retain a distinctly crystalline condition; so that, when they are present in large proportion, they impart a more or less crystalline aspect to the mass, and especially a crystalline mode of fracture, which is evident enough in many shells. It must not be hence concluded, however, that such substances are of an inorganic nature; all that is shown by their crystalline structure being, that the animal basis exists in comparatively small amount, and that the mode in which the mineral matter was deposited has not interfered with its crystalline aggregation.

9. It is not to be disputed that a certain degree of homogeneity is apparently to be found in the *minutest* elements, into which certain Organized tissues are to be resolved. Thus, in the *membranes* which form the walls of Animal and Vegetable cells, the highest powers of the microscope fail in detecting any such distinction of fluid and solid components, as that which has been described as characteristic of organized structures. Nevertheless it is indubitable that such distinct components *must* exist; and this especially from the properties of these membranes in regard to water. For it is one of the most remarkable facts in the whole range of science, that a *membrane* in which not the slightest appearance of a pore can be discovered under the highest powers of the microscope, should be capable of allowing water to pass through it: and that, too, with no inconsiderable rapidity. The change which these membranes undergo in drying, is another proof that they are not so homogeneous as they appear, and that water is an element of their structure, not merely chemically, but mechanically. The same may be said in regard to the *fibres* which form the apparently-ultimate elements of the simple fibrous tissues in Animals, and which are also met-with in the interior of certain cells and vessels in Plants. These fibres would appear to be of perfectly simple structure; yet we know from the loss of fluid and the change of properties which they undergo in drying, that water must have formed part of their substance.—It may be remarked, however, in regard to both these elementary forms of Organized tissue, that the simplicity of their function is in complete conformity with the apparent homogeneousness of their structure; for the cell-membrane is chiefly destined to act, like the porous septum in certain forms of the voltaic battery, as a boundary-wall to the contained fluid, without altogether interfering with its passage elsewhere; the forces which produce its imbibition or expulsion being probably situated, not in this pervious wall, but in the cavity which it bounds. And, in the same

manner, the function of the fibrous tissues, to which allusion was just-now made, is of an entirely-physical character; being simply to resist strain or tension, and yet to allow of a certain degree of yielding by their elasticity.

10. In all cases in which active Vital operations are going-on, we find, in the structures subservient to them, a very obvious distinction into liquid and solid parts; and it is, indeed, by the continual reaction which is taking-place between these, that the fabric is maintained in its normal condition. For, as we shall hereafter see, it is liable to a constant decomposition or separation into its ultimate elements; and it is consequently necessary that the matters which have undergone that disintegration should be carried-off, and that they should be replaced by new particles. These processes of removal and replacement, with the various actions subservient to them, make-up a large proportion of the life of every Organized being. Now as all the alimentary matter must be reduced to the liquid form, in order that it may be conveyed to the situations in which it is required, and as all the decomposed or disintegrated matter must be reduced to the same form in order to be carried-off, the intermingling or mutual penetration of solids and liquids in the minutest parts of the body is at once accounted for. We shall hereafter see that a *cell*, or closed vesicle, formed of a membranous wall and fluid contents, may be regarded as one of the simplest forms of a living body, and the simplest independent part or instrument of the more complex fabrics (§ 21).

11. Organized structures are further distinguished from Inorganic masses, by the peculiarity of their *chemical constitution*. This peculiarity does not consist, however, in the presence of any elementary substances which are not found elsewhere; for all the elements of which organized bodies are composed, exist abundantly in the world around. It might have been supposed that beings endowed with such remarkable powers as those of Animals and Plants,—powers which depend, as we shall hereafter see, upon the exercise of properties to which we find nothing analogous in the Mineral world,—would have had an entirely different material constitution; but a little reflection will show, that the identity of the ultimate elements of Organized structures with those of the Inorganic world, is a necessary consequence of the mode in which the former are built-up. For that which the parent communicates in giving origin to a new being, is not the structure itself, but the capacity to form that structure from the surrounding elements; and it is by gradually drawing to itself certain of these elements, that the germ becomes developed into the complete fabric. Now, of the *sixty-three* simple or elementary substances which are known to occur in the Mineral world, only about *eighteen* or *nineteen* are found in Plants and Animals; and many of these in extremely minute proportion. Some of these appear to be introduced, merely

to answer certain chemical or mechanical purposes; and the composition of the parts which possess the highest vital endowments, is for the most part simpler and more uniform.

12. The actual *tissues* of Plants, when entirely freed from the substances they may contain, have been found to possess a very uniform composition, and to agree in their chemical properties. The substance which forms the principal part of the thickness of the walls of the cells, vessels, &c., of which the Vegetable organism is composed, is identical with *Starch* in the proportions of its components; but as these are in a different state of aggregation, it is distinguished as *Cellulose*. It consists of 12 Carbon, 10 Hydrogen, and 10 Oxygen; or, in other words, of Carbon united to the elements of Water. Now there is no compound known to exist in the Inorganic world, which bears the remotest analogy to this; and we have not at present any reason to believe that it could be produced in any other way, than by that peculiar combination of forces which exists in the growing Plant.—But although Cellulose is the predominating component of the Vegetable fabric, yet it is not the most essential; for within what has been ordinarily considered as the cell-wall, is a delicate membrane termed the 'primordial utricle,' which is really the original cell-wall from whose exterior the cellulose-envelope is secreted;* and this is lined (at least in the active condition of the cell) by a layer of 'protoplasm,' a viscid liquid which is the formative material of all vegetable tissue; and both the one and the other contain an *Albuminous* compound, in which the formative power seems especially to inhere. Hence every act of Vegetable growth involves the production of this substance also, which is still more removed in its composition from ordinary Inorganic compounds.

13. The composition of the Animal tissues, when freed from the solid matters which may have been deposited within them, is nearly as uniform. The chief material of the 'blastema' or formative liquid at whose expense they are all developed, and the fundamental constituent of all such as agree with the Vegetable tissues in their *cellular* character, is *Albumen;* which is composed of 40 Carbon, 31 Hydrogen, 5 Nitrogen, and 12 Oxygen, with a minute proportion of Sulphur and Phosphorus. But those *simple fibrous* tissues having none but a purely mechanical function, of which a large part of the fabric of the higher Animals is made up, have as their basis a substance that is converted by boiling into *Gelatine ;* which consists of 13 Carbon, 10 Hydrogen, 2 Nitrogen, and 5 Oxygen. There is ample evidence that the gelatinous tissues derive their material from the albuminous 'blastema' which serves as the pabulum to the rest; but although albumen can be converted into

* The 'primordial utricle' may probably be considered as the external layer of the 'protoplasm' that encloses the other cell-contents, which has undergone a certain degree of consolidation.

elatine in the living body, gelatine cannot be converted into bumen, so that it is quite incapable of affording nourishment to buminous tissues, or even of contributing towards the formation the organizable blastema.

14. As we shall hereafter dwell more in detail upon the Chemi-l Constitution of the Animal tissues and products (CHAP. III.), iese substances are only noticed here in illustration of the general atement, that the 'proximate principles' of Animal and Vegetable odies (that is, the simplest forms to which their component ructures can be reduced, without altogether separating them into ieir ultimate elements) are of extremely peculiar constitution; eing made-up of three or four elements, of which the atoms do ot seem to be united two by two, or by the method of *binary* omposition, but of which a large number are brought-together form one *compound atom*, of *ternary* or *quaternary* composition. his compound atom, like Cyanogen and many others derived om Organic products, acts like a simple or elementary one in its ombinations with other substances.—It is worthy of remark, owever, that, in this respect as in others, the Vegetable kingdom intermediate between the Animal and the Mineral. For whilst lbumen and Gelatine are remarkable, not only for containing *our* elements, but for the very large number of atoms of their omponents which enter into the single compound atom of each, he Cellulose of Plants is much simpler in its composition, since it icludes only *three* elements, and the numbers which represent heir proportions are smaller. And further, the proportions of the omponents of Cellulose are themselves such as suggest the idea f simplicity in their method of combination, by the union of ater and carbon in the common binary method;—an idea which s confirmed by the mode of its original production, which indi-ates a direct union of carbon with water; as well as by the fact hat the chemical difference between cellulose and numerous other ubstances found in Plants, may be represented by the simple ddition or subtraction of a certain number of atoms of water, and hat the chemist can effect an actual conversion of the former into ertain of the latter, by means which are calculated to effect such n addition or subtraction.

15. We shall hereafter see that Vegetables are intermediate etween the Animal kingdom and the Inorganic world in another nost important particular—the nature of the Chemical operations hey effect; for it is their function to combine the oxygen, hydro-gen, carbon, and nitrogen of the Inorganic world, into Organic Compounds; which not only serve as the materials of their own rowth, but also as the food of Animals, whose existence is en-irely dependent upon them, since *they* possess no such combining ower. It is from the Water, Carbonic acid, and Ammonia, sup-lied by the atmosphere and by the soil in which they are fixed,

that Plants derive these elements. On the other hand, the Animal, making use of the ternary and quaternary compounds which have been elaborated by Plants, is continually breaking up these compounds, and restoring their components to the Inorganic world, in the very forms which they originally possessed; for, as we shall hereafter see, the excretion of Water, Carbonic acid, and Ammonia is constantly taking-place in the living Animal body, as the result of those changes in which its peculiar activity consists (§ 197); whilst these same binary compounds are set-free (with others) during the decomposition of the same body after its death. And thus is sustained that balance between Animal and Vegetable nutrition, which is found to be the more wonderful and complete, the more carefully it is scrutinized.

2. *Distinctive Characters of Vital Actions.*

16. We are now arrived at the second head of our inquiry,—namely, the nature of those *actions* which distinguish living beings from masses of inert matter, and which are designated as *Vital*, to mark their distinctness from Physical and Chemical phenomena. There can be no doubt whatever, that, of the many changes which take place during the *life*, or state of *vital activity*, of an Organized being, and which intervene between its first development and its final decay, a large proportion are effected by the direct agency of those forces which operate in the Inorganic world; and there is no necessity whatever for the supposition that these forces have any other operation *in* the living body, than they would have *out* of it under similar circumstances. Thus the propulsion of the blood by the heart through the large vessels, is a phenomenon precisely analogous to the propulsion of any other liquid through a system of pipes by means of a forcing pump; and if the arrangement of the tubes, the elasticity of their walls, the contractile power of the heart, and the physical properties of the fluid, could be precisely imitated, the artificial apparatus would give us an exact representation of the actions of the real one. The motor force of the muscles upon the bones, again, operates in a mode that might be precisely represented by an arrangement of cords and levers; the peculiarity here, as in the former case, being solely in the mode in which the force is first generated. So, again, the digestive operations which take-place in the stomach are capable of being closely imitated in the laboratory of the chemist; when the same solvent fluid is employed, and the same agencies of heat, motion, &c., are brought into play. Moreover we shall hereafter see reason to believe, that the peculiar form of capillary attraction, to which the term 'endosmose' is applied, performs an important part in the changes which are continually occurring in the living body.

17. But after every possible allowance has been made for the operation of Physical and Chemical forces in the living Organism,

re still remains a large number of phenomena which cannot be the least explained by them, and which we can only investigate th success, when we regard them as resulting from the agency forces as distinct from those of Physics and Chemistry, as *they* from each other. It is to these phenomena that we give the me of *Vital;* the forces from whose operation we assume them result, are termed *vital forces;* and the properties which we must ribute to the substances manifesting those forces, are termed *al properties.* Thus we say that the *act of contraction* in a mus- is a *vital phenomenon,* because its character appears totally dis- ct from that of any Physical or Chemical action, and because it dependent upon other vital changes in the muscular substance. e act is the manifestation of a certain *force,* the possession of ich is peculiar to the muscular structure, and which is named *Contractile force.* But that force is only exerted under certain nditions, and these may only recur at long intervals, though the pacity for exerting it may be constantly present in the organized sue; this capacity is termed a *property;* and thus we regard it the essential peculiarity of living Muscular tissue, that it pos- sses the vital property of *Contractility.* Or, to reverse the order, muscle is said to possess the property of Contractility; the pro- rty, when the appropriate conditions are supplied, gives rise to Contractile Force; and the Force produces, if its operations be opposed, the act of Contraction.

18. It may be said that the distinction here made is a verbal e, and that a very simple thing is thus made complex; but it ll be presently seen that such a distinction is necessary, in order enable us to take correct views of the nature of Vital pheno- ena, and to understand their relations to those of the Inorganic orld. And, in fact, the difference between the *property,* the *rce,* and the *action,* becomes apparent upon a little consideration. f the 'property' we are altogether unconscious so long as it is t called into exercise; we could not, for example, determine by e direct use of any of our senses, whether a certain piece of uscle retained or had lost its contractility, any more than we n tell by its appearance alone whether or not a piece of iron is agnetic. When the property is called into action by its appro- iate stimulus, we may convince ourselves that a 'force' is ge- rated, even if no sensible movement result: thus, if we were to ld the two extremities of a muscle so firmly as to prevent them om approximating in the least degree when its contractility was cited, we should be conscious of a powerful force tending to aw our hands together; and we might measure the amount of at force by mechanical means adapted to determine the weight would sustain. And lastly, if no obstacle be interposed to the act' of contraction, it is then made obvious to our senses by the ange in the shape of the muscle, and by the approximation of its

two extremities, as well as of the bones to which they are attached.

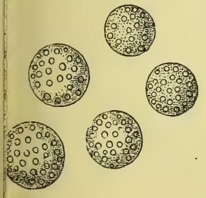
19. It is hoped that the propriety of the distinct use of the terms *Vital Action*, *Vital Force*, and *Vital Property*, will now be evident; and that the student will be prepared to attach definite ideas to each of them. It is the business of the Physiologist to study those actions or phenomena which are peculiar to living beings and which are hence termed *vital*:—he endeavours to trace them to the operation of specific forces acting through organized structures, just as the Astronomer traces all the movements, regular and perturbed, of the heavenly bodies, to the mutual attraction of their masses, acting concurrently with their force of onward rectilinear movement; or as the Chemist attributes the different acts of combination or separation which it is his province to study, to the mutual affinities of the substances concerned:—and the physiologist, like the astronomer or the chemist, seeks to determine the *laws* according to which these forces operate, or, in other words to express in general terms the precise conditions under which they come into play, and the actions they then produce.

20. It is only in this manner, that Physiology can be rightly studied and brought to the level of other sciences. There can be no doubt that its progress has been greatly retarded by the assumption, that its phenomena were all to be attributed to the operation of some general controlling agency or Vital Principle and that the laws expressing the conditions of these phenomena must be sought-for by methods of investigation entirely distinct from those which are employed in other sciences. But a better spirit is now abroad; and the student cannot be too strongly urged to discard any ideas of this kind, as absolutely untenable; and to keep steadfastly in view, that the laws of Vital Action are to be attained in the same manner as those of Physics or Chemistry,—that is, by the careful collection and comparison of vital phenomena, and by applying to them the same method of reasoning as that which is used in determining the forces and properties on which other phenomena depend. True it is, that we can scarcely yet hope to reach the same degree of simplification, as that of which other sciences are capable; but this merely results from the very complex nature of the phenomena themselves, and the difficulty of satisfactorily determining their conditions. The uncertainty of the results of Physiological experiments is almost proverbial: that uncertainty does not result, however, from any want of fixity in the conditions under which the Vital forces operate, but merely from the influence of differences in those conditions, apparently so slight as to elude observation, and yet sufficiently powerful to produce an entire change in the result. And, owing to that mutual dependence of the several actions of the organized structure, to which reference has been already made

5), we cannot seriously derange one class of these actions, ithout also deranging or even suspending others;—a circumance which obviously renders Vital phenomena much more diffiult of investigation than those of Inorganic matter.

21. In the study of any branch of science, it is most desirable commence with definite views of the nature of the phenomena ith which it is concerned; and such are best gained by the exnination of these phenomena under their simplest aspects. This ourse is most especially necessary in Physiology; since the comexity of the conditions under which its phenomena usually esent themselves, often tends to mask their real character, causg that to be regarded as essential which is only accidental or ontingent, and *vice versâ.* It is extremely difficult, however, and equently impossible, for the Physiologist to isolate these several onditions, and to study them separately, in the way that the hemical or Physical investigator would do; and his best course to take advantage of those "experiments ready prepared y Nature," which he finds in the variety of forms of living ganized beings with which this globe is so richly peopled. Now is in the simplest forms of Cryptogamic Vegetation, that the henomena of Life present themselves under their least compliated aspect; for we shall find in the operations of each of those mple cells of which such Plants are composed (all of them rembling one another in structure and actions), an *epitome*, as it ere, of those of the highest and most complex Plant; whilst iose of the higher Plants bear a close correspondence with those hich are immediately concerned in the Nutrition and Reproducon of the Animal body.—A *Cell*, then, in the language of Physiology, is a closed vesicle or minute bag, formed by a membrane in which no definite structure can be discerned, and having a cavity which may contain matters of variable consistence; but which possesses in itself the power of growth, and (in its typical condition at least) of multiplication also. Such a cell constitutes the entire organism of such simple plants as the *Protococcus nivalis* ('red snow'), or *Palmella cruenta* ('gory dew'); for although the patches of this kind of vegetation hich attract our notice are made up of vast aggregations of such ells, yet these have no dependence one upon another, and the ctions of each are an exact repetition of those of the rest. In uch a cell, every organized fabric, however complex, originates. he vast *tree*, almost a forest in itself, and the feeling, thinking,

Fig. 1.*



* Simple isolated Cells, containing reproductive corpuscles.

intelligent *man*, spring from a germ, that differs in no obvious particular from the permanent condition of one of these lowly beings. But whilst the powers of the latter are restricted, as we shall see, to the continual multiplication of new and distinct individuals like itself, those of the former enable it to produce new cells that remain in closer connection with each other; and these are gradually converted, by various transformations of their own, into the diversified elements of a complex fabric. The most highly-organized being, however, will be shown to consist in great part of cells that have undergone no such transformation, amongst which the different functions performed by the individual in the case just cited, are distributed, so to speak; so that each cell has its particular object in the general economy, whilst the history of its own life is essentially the same as if it were maintaining a separate existence.

22. We shall now examine the history of the solitary cell of one of the simplest Cryptogamic Plants, from its first development to its final decay; in other words, we shall note those Vital Phenomena which are as distinct from those of any inorganic body, as is its organized structure (simple as it appears) from the mere aggregation of particles in a mineral mass.—In the first place, the cell takes its origin from a *germ*, which may be a minute *molecule* that cannot be seen without a microscope of high power. This molecule appears, in its earliest condition, to be a simple homogeneous particle, of spherical form; but it gradually increases in size, and a distinction becomes apparent between its transparent exterior and its coloured interior. Thus we have the first indication of the *cell-wall*, and the *cavity*. As the enlargement proceeds, the distinction becomes more obvious; the cell-wall is seen to be of extreme tenuity and perfectly transparent; whilst the contents of the cavity are distinguished by their colour, which is very commonly either green or crimson. The outer cell-wall, which (as already stated, § 12) is composed of Cellulose, may be considered as a secretion from the surface of the 'protoplasmic' layer that lines it, and seems entirely destitute of other than *physical* properties. It is in the protoplasmic layer alone that the *vital* powers exerted by the cell appear to be inherent; and when the 'agency of the cell' is spoken of, the phrase is to be understood as referring exclusively to that one of its components. The whole mass of 'endochrome' (that is, of the coloured contents of the cell) sometimes subdivides into two or more parts, each of which is invested by a protoplasmic layer, and may ultimately isolate itself completely by the formation of a wall of cellulose. But sometimes we see little particles projecting from the lining of the cell, which seem to be offsets from the protoplasmic layer; these move about in the cavity, and at last escape by an opening that forms itself in the cell-wall, swimming-forth with such activity as to resemble Animalcules. Of these 'zoospores,' as

hey are termed, every one may develope itself into a cell precisely fter the foregoing manner, and will then in its turn multiply its ind by a similar process.

23. By reasoning upon the foregoing history, we may arrive at ertain conclusions which will be found equally applicable to all ving beings. In the first place, the cell originates in a germ or eproductive body, which has been prepared by another similar cell at previously existed. There is no sufficient reason to believe at any exception to this rule exists; for so far as we at present now, every Plant and every Animal is the offspring of a parent, which it bears a resemblance in all essential particulars. But ow does this *germ*, this apparently homogeneous molecule, become Cell? The answer to this is only to be found in its peculiar roperty of drawing materials to itself from the elements around, nd of incorporating these with its own substance. The Vegetable ell may grow wherever it can obtain a supply of water, carbonic cid, and ammonia; for these compounds supply it with oxygen, ydrogen, carbon, and nitrogen, in the state most adapted for the xercise of its peculiar combining power, by which it converts them ito those new compounds, whose properties adapt them to become art of the growing organized fabric. Here, then, we have two istinct operations;—the union of these elementary substances ito the Organic Compounds which serve as the materials of the egetable tissues;—and the incorporation of those products with e substance of the germ itself. Starch, Cellulose, and Sugar all onsist of Carbon united with the elements of Water; the proporon being 12 of the former to 10 of the latter in the case of the rst two, and 12 of the former to 11 of the latter in the case of the ird. Hence, as carbonic acid contains its own bulk of oxygen, at element must be set-free, whenever Starch, Cellulose, or Sugar formed by the union of the Carbon of carbonic acid with the ements of Water, in the process of vegetable growth. So it can e shown that when Vegetable Albumen is formed at the expense Water, Carbonic Acid, and Ammonia, there must be a disengement of oxygen in the course of the re-arrangement of their ements which then takes-place. This result of the nutritive opetions of the simple Cellular Plants may be easily verified expementally, by exposing the green scum which floats upon ponds, tches, &c., and which consists of the cells of a minute Cryptomic Plant, to the influence of light and warmth beneath a reiver; it is found that oxygen is then liberated by the decompotion of the carbonic acid contained in the water.

24. The *first* of these changes *may be*, and probably *is*, of a rely *Chemical* nature; and analogous cases are not wanting in e domain of Inorganic Chemistry, in which one body, A, exerts influence upon two other bodies, B and C, so as to occasion their paration or their union, without itself undergoing any change.

Thus platinum, in a finely-divided state, will cause the union of oxygen and hydrogen at ordinary temperatures; and finely-powdered glass will do the same at the temperature of 572°. This kind of action is called *catalysis.*—A closer resemblance, perhaps, is presented by the act of *fermentation ;* in which a new arrangement of particles is brought-about in a certain compound, by the presence of another body which is itself undergoing change, but which does not communicate any of its elements to the new products. Thus, if a small portion of animal membrane in a certain stage of decomposition be placed in a solution of Sugar, it will occasion a new arrangement of its elements, whereby two new products are generated, Alcohol and Carbonic acid. If the decomposition of the membrane have proceeded further, a different product will result; for instead of alcohol, Lactic acid will be formed. And in a further stage of decomposition, the ferment is the means of producing Butyric acid (the fatty acid of rancid butter). There appears no improbability, then, in the idea, that the influence exerted by the germinal molecule is of an analogous nature; and that it operates upon the elements of the surrounding water and carbonic acid, according to purely Chemical laws, uniting the carbon with the elements of water, and setting-free the oxygen.—This change can only be effected, however, when the Vegetable germ is acted on by Solar Light and Heat; and we shall hereafter see that these are the *powers* really concerned in effecting the transformation, the germ being merely the *instrument* through which they operate.

25. The *second* stage in the nutritive process, consists in the appropriation of the new products thus generated to the enlargement of the living cell-structure; a phenomenon obviously distinct from the preceding. It is well to observe, that this process, which constitutes the act of *Organization*, may be clearly distinguished in the higher Plants and Animals, as consisting of two stages;—the first of these being that of *Assimilation*, which consists in the further preparation or elaboration of the fluid matter, by certain alterations whose nature is not yet clear, so as to render it *plastic* or *organizable ;*—the second being the act of *Formation*, or the conversion of such organizable matter into the solid texture, in which process the properties that distinguish that texture come to manifest themselves. Thus, for example, we do not find that a solution of dextrin (or starch-gum) is capable of being at once applied to the development of Vegetable tissue, although it is identical in composition with cellulose; for it must be worked-up with albuminous matter into that peculiar glutinous substance termed *protoplasm*, which is present wherever cell-development is taking place. And in like manner, the albumen of Animals does not seem capable of being applied to the formation of tissue, until it has been first converted into the organizable *blastema* (of which we have a specimen in the plastic exudation poured-out for t

reparation of injuries), distinguished by its tenacious character, by its spontaneous coagulability, and by the fibrous structure of its clot.

26. Now in both these cases there is probably some slight modification in Chemical composition, that is, in the proportions of the ultimate elements; but this is quite insufficient to account for the very marked differences which show themselves between the Organizable and the Unorganizable fluids. Such differences display themselves in the most striking manner in various forms of diseased action, which essentially depend on a deficient organizability of the nutrient materials; these materials being converted into low and incomplete forms of structure, instead of being developed into normal tissue; and showing a greater tendency to degeneration and decay, than that which characterizes the well-elaborated or plastic substances that are thoroughly fitted for taking their place as constituents of the living organism.—The process of *Assimilation*, then, seems essentially to consist in the incipient *vitalization* of materials which were previously in the condition of mere chemical compounds. And it is interesting to remark, that in all cases in which we can trace it out, we have reason to believe that the *progressive* metamorphosis of one portion of these materials is accompanied by the *retrograde* metamorphosis of another part, which is resolved by decomposition into the binary compounds at the expense of which it was originally generated. This circumstance will be found to have an important bearing upon the question hereafter to be considered (§ 59) as to the source of the Vital Force thus imparted to substances previously destitute of it. The spontaneous coagulation of fibrin, which takes place very soon after it has been withdrawn from the vessels of the living body, is a phenomenon to which nothing analogous can be found elsewhere; for it has been clearly shown not to be occasioned by any mere physical or chemical change in its constitution; and it occurs in a manner which indicates that a new arrangement of particles has been effected in it, preparatory to its being converted into a living solid. For this coagulation is not the mere homogeneous 'setting' which takes-place in a solution of gelatine in cooling; nor is it the aggregation of particles in a mere granular state (closely resembling that of a chemical precipitate), which takes-place in the coagulation of albumen: it is the actual production of a simple *fibrous tissue*, by the union of particles of fibrin in a determinate manner, bearing a close resemblance to the similar process in the living body (§ 187). We say, then, that the coagulation of Fibrin, and the production of a fibrous tissue, are the manifestation of its *vital* properties, rather than the direct result of chemical or physical agencies; because no substance is known to perform any such actions, without having been subjected to the influence of a living body; and because the actions themselves are altogether different from any which we witness elsewhere.

27. The act of Formation seems to consist of a continuation of the same kind of change;—that is, a new arrangement of the particles, together with a more complete vitalization, produce substances which differ both as to structure and properties from the materials employed, though so closely allied to them in chemical composition that the difference scarcely can be detected. Thus, from the 'protoplasm' of the Plant are generated, in the process of the development of its cells, the various component parts of each of these integers: chemically speaking, there seems to be no essential distinction between these substances; and yet between the living, growing, reproducing cell, and the gelatinous, semifluid matter in which they originate, how wide the difference! So in the Animal body, we find that the substance of the proper muscular tissue scarcely differs, in regard to the proportion of its elements, from the albumen of the blood; and yet what an entire re-arrangement must take-place in the particles of the latter, before a tissue so complex in structure, and so peculiar in properties, as muscular fibre, can be generated!

28. Both in the Plant and the Animal, moreover, we find that tissues presenting great diversities both in structure and properties, may take their origin in the same organizable material; but in every case (at least in the ordinary processes of growth and reparation) the new tissue of each kind is formed *in continuity* with that previously existing. Thus in the stem of a growing Tree, from the very same glutinous sap or 'cambium' intervening between the wood and the bark, the wood generates, in contact with its last-formed layer, a new cylinder of wood; whilst the bark produces, in contact with *its* last-formed layer, a new cylinder of bark; the woody cylinder being characterized by the predominance of ligneous fibre and ducts, and the cortical by the predominance of peculiar kinds of cellular tissue. In like manner we find, that, in Animals, muscle produces muscle, bone generates bone, nerve developes nerve, in continuity with itself, — all at the expense of the materials supplied by the very same blood.

29. The *Nutrition* of tissues, by the organization of the materials contained in the nutrient fluid with which they are supplied, may be superficially compared, therefore, to the act of crystallization, when it takes-place in a mixed solution of two or more salts. If in such a solution we place small crystals of the salts it contains, these crystals will progressively increase by their attraction for the other particles of the same kind which were previously dissolved; each crystal attracting the particles of its own salt, and exerting no influence over the rest. And it is curious that if either of the crystals be broken, the new deposit will take-place upon it in such a mode as gradually to reproduce its characteristic form.—But it must be borne in mind that such a resemblance goes no farther than the surface; for the growth of a crystal cannot be

ɜally regarded as in the least analogous to that of a cell. The rystal progressively increases by the deposit of particles upon its xterior; the interior undergoes no change; and whatever may e the size it ultimately attains, its properties remain precisely the ıme as those of the original nucleus. On the other hand, the ell grows from its original germ by a process of *interstitial* de-osit; the component substance of its wall extends itself in every art; and the new matter is completely incorporated with the old.

30. Moreover, as the increase proceeds, we see an evident dis-ınction between the cell-wall and its cavity; and we observe, that ıe cavity is occupied by a peculiar matter, different from the sub-tance of the cell-wall, though obviously introduced through it.)f the essential difference which may exist in composition between ıe cell-wall and the contents of the cavity, we have a remark-ble example in the case of the simple Cryptogamic plant that onstitutes Yeast, which differs in no essential part of the history f its growth from the examples already referred to. The principal omponent of its cell-walls is nearly identical with ordinary cellu-ɔse; whilst the contents of the cells are closely allied in com-osition to albumen. Again, in the fat-cells of Animals, the cell-rall is formed from an albuminous compound; whilst the oily ontents rather correspond in the absence of nitrogen and in their ɜrnary composition with the materials of the tissues of Plants. t is evident, then, that one of the powers inherent in the cell, is hat which not only combines the surrounding materials into substance adapted for the extension of its *wall*, but that which xercises a similar combining power on other materials de-ived from the same source, and forms a compound, — of an ntirely different character, it may be, — which occupies its *cavity*. Now this process is as essential to our idea of a living cell, as is he growth of its wall; and it must never be left out of view, vhen we are considering the history of its development.

31. Every kind of cell has its own specific endowments; and enerates in its interior a compound peculiar to itself. The nature f this compound is much less dependent upon the nutrient ma-erials which are supplied to the cell, than upon the original in-ıerent powers of the cell itself, derived from its germ. Thus we ind that the 'red snow' and 'gory dew' invariably form a peculiar ed secretion; and that they will only grow where they can obtain rom the air and moisture around, the elements of that secretion. Again, the 'yeast-plant' invariably forms a secretion analogous to ınimal albumen; and it will only grow in a fluid which supplies it vith the materials of that substance. Hence the 'red snow' vould not grow in a fermentible saccharine fluid; nor would the yeast plant' vegetate on damp cold surfaces. Yet there is little lifference, if any, between their cell-walls, in regard to chemical omposition.—So, also, we shall find hereafter that one set of cells

in the animal body will draw into themselves, during the process of growth, the elements of bile; another, the elements of milk; another, fatty matter; and so on; the peculiar endowments of each being derived from their several germs, which seem to have an attraction for these substances respectively, and which thus draw them together; whilst the cell-wall appears to have a uniform composition in all instances.

32. The term *Secretion* or setting apart, is commonly applied to this operation, to distinguish it from Nutrition or growth; but it is obvious from what has now been stated, that the act of secretion is in reality the increase or growth of the cell-contents, just as the process of enlargement is the increase or growth of the cell-wall; and that the two together make up the whole process of Nutrition, which cannot be properly understood unless both are taken into account. It is to be remembered, however, that the *contents* of the cell may not be destined to undergo organization; indeed we shall find hereafter, that the main use of certain cells is to draw-off from the circulating fluid such materials as are incapable of organization; and the operation may be so far attributed, therefore, to the agency of Chemical forces. But we shall find that, in other instances, the cell-contents *are* destined to undergo organization, and this either within the parent-cell, or after they leave it; here, then, we must recognize a vitalizing influence, as exerted by some agency within the cell upon its contents.

33. This organizing or vitalizing influence must be exerted upon a certain portion of the contents of every cell that is capable of reproducing itself; for it is in this manner that those germs are produced, in which all the wonderful properties of the parental organism are inherent. This power of *Reproduction* is one of those which most remarkably distinguishes the living being; and we shall find that in the highest Animal, as in the humblest Plant, it essentially consists in the preparation of a cell-germ, which, when set free, gradually developes itself into a structure like that from which it sprang. The reproductive molecules or cell-germs are formed, like the tissue and the contents of the parent-cell, from the nutrient materials which it has the power of bringing together and combining; in their turn they pass through a corresponding series of changes; and at length they produce a new generation of similar molecules, by which the race is destined to be continued. Notwithstanding the mystery which has been supposed to attach itself to this process, it is obvious that there is nothing in reality more difficult to understand in the fact, that the protoplasm of the parent-cell organizes and vitalizes the product which it has elaborated, so as to form the germ of a *new* individual possessing similar properties with itself, than in its incorporating the same material with *its own* structure, and causing it to take a share in its own actions. And, in fact, we find that among the

wer tribes of Plants and Animals, the processes of Growth and production are often scarcely distinguishable from each other.

34. Finally, the parent-cell having arrived at its full development, having passed through the whole series of changes which characteristic of the species, and having prepared the germs by ich the race is to be propagated, *dies* and *decays ;* that is, all ose operations which distinguish living organized structures m inert matter, cease to be performed; and it is given up to the fluence of Chemical forces only, which speedily occasion a seration of its elements, and cause them to return to their original rms, namely, water, carbonic acid, and ammonia.—It is not, wever, in the dead organism alone, that this decomposition curs; for it is certain that *interstitial* death and decay are inssantly taking-place during the whole life of the being; and at the maintenance of its healthy or normal condition depends on the constant removal of the products of that decay, and upon eir continual replacement. If, on the one hand, those products be tained, they act in the manner of poisons; being quite as injuus to the welfare of the body as the most deleterious subnces introduced from without. On the other hand, if they be ly carried-off, but be not replaced, the conditions essential to al action are not fulfilled, and the death of the organism must the result.

35. Now it is to be observed that, as Plants obtain the chief terials of their *growth* from water and carbonic acid, taking the rbon from the latter and setting-free the oxygen, so do they quire, as the condition for their *decay*, the presence of oxygen, ich may reunite with the carbon that is to be given back to the mosphere. If secluded from this, the vegetable tissues may be eserved for a long time without decomposition. Generally eaking, indeed, they are not prone to rapid decay, except at a gh temperature; and hence it is that we have so little evidence, Plants, of that constant interstitial change of which mention s just been made. Its existence, however (at least in all the ter portions of the structure), is made evident by the fact, that ontinual extrication of carbonic acid takes-place, to an amount ich sometimes nearly equals that of the carbonic acid decomsed, and of the oxygen set-free, in the act of Nutrition (§ 23). e latter operation is only effected under the stimulus of sunht; the former is constantly going-on, by day and by night, in nshine and in shade; and if it be impeded or prevented by want a due supply of oxygen, the plant speedily becomes unhealthy. Now this extrication of the products of interstitial decay is med *Excretion*. It is usually confined in Plants to the forman of carbonic acid and water, by the union of their conponent bstances with the oxygen of the air; a process identical with at which occurs after the death of the entire structure. But in

Animals it is much more complicated, owing to the larger number of constituents in their fabric, and to the much greater variety in the proportions in which these are combined; hence the products of interstitial decomposition are much more numerous and varied, and several distinct modes are devised for getting-rid of them. Moreover, as the Animal tissues are much further removed than the Vegetable from the composition of Inorganic bodies, they are subject to much more rapid and constant decay; and we shall find that this decay is so considerable in amount, as to require on the one hand a very complex excretory apparatus to carry-off the disintegrated matter, and on the other a large supply of nutrient material to replace it.

36. The preceding history may be thus summed up.—I. The presence of the active Vegetable cell-germ or reproductive molecule, under conditions hereafter to be specified (Sect. 3), occasions the combination of certain inorganic elements into new and peculiar compounds. These compounds, however, exhibit no properties that distinguish them from others in which ordinary *Chemical* agencies have been concerned; and we may, therefore, regard the first act of the Vegetable cell-germ as essentially chemical in its nature. The Animal cell-germ does not possess the same properties; it is not capable of decomposing the water, carbonic acid, and ammonia, which include the elements of its tissues; and it is entirely dependent for its growth, upon the supply of nutriment previously prepared for it by the agency of the vegetable kingdom.—II. The cell-germ then exerts an *Assimilating* agency upon the *pabulum* thus prepared; by which a new arrangement of its particles is produced. This new arrangement gives new and peculiar qualities to the fluid, which show that it is something more than a mere chemical compound, and is undergoing the process of vitalization.—III. The *Formation* of this elaborated pabulum into tissue then takes-place; its materials are withdrawn from the fluid, and incorporated with the solid texture; and in thus becoming part of the organized fabric, they are caused to exhibit its own peculiar properties.—IV. At the same time, another portion of this pabulum may be gradually prepared to serve as the germ of a new cell, or set of cells, by which the same properties are to be exhibited in another generation.—V. By an operation resembling that concerned in the first preparation of the pabulum, certain products, more or less differing from it in character, but not destined to undergo organization, are formed in the cavity of the cell.—VI. A decomposition or disintegration of the organized structure is continually going-on, by the separation of its elements into simpler forms, under the influence of purely Chemical attractions; and the setting-free of these products by an act of excretion, is thus incessantly restoring to the Inorganic world a portion of the elements that have been withdrawn from it.—VII. When

ıe term of life of the parent-cell has expired, and its reproducve molecules are prepared to continue the race, the actions of utrition cease; those of decomposition go-on unchecked; and the eath of the structure, or the loss of its distinguishing vital properties, is the result. By the decomposition which then takes lace with increased rapidity, its elements are restored to the Inrganic world; presenting the very same properties as they did hen first withdrawn from it; and becoming capable of being gain employed, by any successive numbers of living beings, to o through the same series of operations.

37. Thus, then, we see that our fundamental idea of the properties of the simplest Living being consists in this;—that it has ıe capability of drawing into its own substance certain of the ements furnished by the inorganic world;—that it forms these ıto new combinations (which the chemist *may* find out methods f imitating); that it re-arranges the particles of these combinaons in that peculiar mode which we call 'organization;'—that ı producing this new arrangement, it renders them capable of xhibiting a new set of properties which we call 'vital,' and hich are manifested by them either as connected with the parent rganism or as appertaining to the germs of new structures, acording to the mode in which the materials are applied;—that otwithstanding its peculiar condition, it remains subject to the rdinary laws of Chemistry, and that decomposition of its structure is continually taking-place; and finally, that the duration f its vital activity is limited, the changes which the organic ructure undergoes in exhibiting its peculiar actions, being such s to render it (after a longer or shorter continuance of them) ıcapable of any longer performing them.

38. There is abundant evidence that the duration of the *Life*, or ate of *Vital Activity*, of an organized structure, is inversely proortioned to the degree of that activity; and consequently, that ife is shortened by an increased or abnormal activity, whilst it ıay often be prolonged by influences which diminish that activity. his *inverse* relation between the vital activity of a part and the uration of its life is well seen in comparing the transitory existence of the *leaves* of a Plant, which are its active organs of utrition, with the comparative permanence of its woody *stem*, ıe parts of which, when once completely formed, undergo very ttle subsequent change. The most striking manifestation of this onnection, however, is afforded by that condition, in which, ithout any appreciable amount of vital activity or change, an rganized structure may remain unaltered for centuries; not only resenting at the end of that time its original structure, but being repared to go through its regular series of vital operations, as if ıese had never been interrupted. This state may be designated s *Dormant Vitality*. It differs, on the one hand, from *Life;*

because Life is a state of *activity*. On the other hand, it differs from *Death;* because death implies not merely a suspension of activity, but a total *loss of vital properties*. Now in the state of Dormant vitality, the vital properties are retained; but they are prevented from manifesting themselves by the want of the necessary conditions. When these conditions are supplied, the state of vital activity is resumed, and all the functions of life go on with energy.

39. Of this Dormant Vitality it may be well to adduce some examples which may assist in impressing on the mind of the student the general views here put-forth. This condition is manifested in the most remarkable manner by the seeds and germs of Plants; many of which are adapted to remain for an unlimited period in a state of perfect repose, and yet are ready to germinate immediately that they meet with the necessary conditions. Thus the sporules of the Fungi, which can only develope themselves in organic matter that is ready to undergo decomposition, seem universally diffused through the atmosphere, and vegetate with the most extraordinary rapidity whenever matter of this sort presents itself. Such at least appears to be the only feasible mode of explaining their appearance, in the forms of Mould, Mildew, &c., on all moist decaying substances; and that there is no improbability in the supposition itself, is shown by the excessive multiplication of these germs, *a single individual* producing not less than *ten millions* of them, so minute as when collected to be scarcely visible to the naked eye, rather resembling thin smoke, and so light as to be wafted by every movement of the atmosphere; so that, in fact, it is difficult to imagine any place from which they can be excluded.*

40. It is certain that an equally tenacious vitality exists in the seeds of higher plants. Those of most species inhabiting tem-

* This view is fully confirmed by the recent very carefully-conducted experiments of Pasteur; who appears to have established that the decomposition of organic liquids in open vessels depends upon the presence of microscopic Fungi and Infusoria, whose germs, conveyed by the atmosphere, sow themselves (as it were) in the congenial soil, in which their development sets up a chemical change analogous to the fermentation produced by the Yeast-plant in a wort holding in solution a mixture of albuminous and saccharine substances. For he has shown that liquids which under ordinary circumstances very readily pass into decomposition, may be prevented from doing so if the air in contact with them be deprived, either by heat or by a simple mechanical filtration, of organic germs that may be diffused through it. Thus let two similar flasks be filled with milk, and the liquid be boiled in each; then if the mouth of one flask be plugged during ebullition with cotton-wool, whilst that of the other is left open, the milk in the former will remain sweet for an unlimited period, whilst that in the latter will turn sour in a few days, and soon afterwards will become putrescent. Or, if the neck of one of the flasks be drawn out into a capillary tube, the orifice of which is turned downwards, the milk it contains will remain unchanged for a great length of time, although the air in the flask is not cut off from communication with the atmosphere.

rate climates are adapted to remain dormant during the winter; ıd may be easily preserved, in dry air, and at a moderate temrature, for many years. Some of those which had been kept in e Herbarium of Tournefort during upwards of a century, were und to have preserved their fertility. Cases are of no unfreıent occurrence, in which ground that has been turned-up, ontaneously produces plants dissimilar to any in their neighurhood. There is no doubt that in some of these cases, the ed is conveyed by the wind, and becomes developed in spots hich afford congenial soil, as already remarked in the case of e Fungi: thus it is commonly observed that clover makes its pearance on soils which have been rendered alkaline by lime, by rewed wood-ashes, or by the burning of weeds. But there are any authentic facts, which can only be explained upon the supsition that the seeds of the newly-appearing plants have lain for long period imbedded in the soil, at such a distance from the surce as to prevent the access of air and moisture; and that, retaing their vitality under these circumstances, they have been excited germination when at last exposed to the requisite conditions. hus Professor Lindley states as a fact, that he has raised three spberry-plants from seeds taken from the stomach of a man hose skeleton was found thirty feet below the surface of the earth, the bottom of a barrow which was opened near Dorchester; as s body had been buried with some coins of the Emperor Hadrian, ere could be no doubt that the seeds were 1600 or 1700 years d. When a seed has been thus preserved for ten years, it may for a hundred, a thousand, or ten thousand, provided that no ange of circumstances either exposes it to decay, or calls its tal properties into activity. Hence in cases where seeds have en imbedded deep in the earth, not by human agency, but by me geological change, it is impossible to say how long since they ay have been produced and buried; as in the following very rious instance:—Some well-diggers in a town on the Penobscot ver, in the State of Maine (New England), about forty miles om the sea, came, at the depth of about twenty feet, upon a ratum of sand; this strongly excited curiosity and interest, om the circumstance that no similar sand was to be found anyhere in the neighbourhood, and that none like it was nearer than e sea-beach. As it was drawn up from the well, it was placed a pile by itself; an unwillingness having been felt to mix it ith the stones and gravel which were also drawn up. But when e work was about to be finished, and the pile of stones and gravel e removed, it was necessary also to remove the sand-heap. his, therefore, was scattered about the spot on which it had been rmed, and was for some time scarcely remembered. In a year or vo, however, it was perceived that a number of small trees had rung from the ground over which the heap of sand had been

strewn. These trees became in their turn objects of strong interest, and care was taken that no injury should come to them. At length it was ascertained that they were Beech-Plum trees; and they actually bore the Beech-Plum, which had never before been seen except immediately upon the sea-shore. The trees had therefore sprung from seeds, which were in the stratum of sea-sand that had been pierced by the well-diggers. By what convulsion they had been thrown there, or how long they had quietly slept beneath the surface, cannot possibly be determined with exactness; but the enormous length of time that must have elapsed since the stratum in which the seeds were buried formed part of the sea-shore, is evident from the accumulation of no less than twenty feet of vegetable mould upon it.

41. Numerous instances will be related in the succeeding Chapter, of the occurrence of a similar condition in fully-developed Plants, and even in Animals of high organization. In some of these it is a regular part of the history of their lives, coming-on periodically like sleep; whilst in others it is capable of being induced at any time, by a withdrawal of some of the conditions essential to vital activity. In regard to all of them, however, it may be observed, that the vitality can only be retained when the organized structure itself is secluded from such influences as would produce its decay. Thus, the hard dry tissue of the seed is but little liable to decomposition; and all that is usually required for the prevention of change in its structure, is seclusion from the free access of air and from moisture, and a steady low or moderate temperature. If a seed be exposed to air and moisture, but the temperature be not high enough to occasion its germination, it will gradually undergo decay, and will consequently lose its vitality. The Animal tissues are more liable, as already mentioned, to spontaneous decomposition; and the only instances in which they can retain their vitality for a lengthened period, without any nutritive actions, are those in which all decomposition is prevented, either by the action of cold, or by the complete deprivation of air or of moisture,—as when Frogs, Snakes, &c., have been preserved for years in an ice-house, or Wheel-Animalcules have been dried upon a slip of glass.

42. The class of phenomena last brought under notice, serves to exhibit in a very remarkable manner the dependence of all Vital Action upon certain *other* conditions than those furnished by the organized structure alone. Thus a seed does not germinate *of itself;* it requires the influence of certain conditions external to itself, namely, warmth, air, and moisture; and it can no more produce a plant without the concurrence of these, than warmth, air, and moisture could produce it without a germ prepared by a pre-existing organism. Now when we come to study these conditions, we find that they may be arranged under two categories, the

material and the *dynamical*. Thus, a seed cannot germinate without sufficient water to bring the contents of its cells into a state in which their chemico-vital reactions can take place; and it must be surrounded with an atmosphere containing oxygen, since without the presence of this element the necessary chemical transformations cannot go on. Thus oxygen and water are the *material* conditions required by the germinating seed; in almost every other case, alimentary matters are required in addition; but these the seed possesses within itself. Even if supplied, however, with an unlimited amount of water and oxygen, the seed cannot germinate unless it be acted-on by Heat; and this, in fact, may be considered with great probability as supplying the *force* of which not merely the chemical transformations, but the growth and development of the tissues of the Plant, are the manifestation. This view will be more fully developed hereafter (Sect. 3).

43. This dependence of *Vital* actions upon certain external Agencies, as well as upon the properties of the Organism which manifest them, is no greater than the dependence of any of the phenomena exhibited by an Inorganic substance upon some other agency external to itself. In fact, *no change whatever can be said to be truly spontaneous;* or, in other words, no Force whatever can produce itself or be produced *de novo*, any more than it can cease to exist. Thus we find chemical changes, consisting in the union of some substances, or in the separation of others, occurring under the influence either of Light, of Heat, of Electricity, or of the Chemical Affinity exerted by the presence of some other substance. The influence of the Dynamical conditions which are essential to Vital activity will be fully explained in the next Chapter; and at present it will be sufficient to remark, that the amount in which they are supplied possesses a well-marked influence upon the amount of activity and energy manifested in the actions of the organized structure; that there is a limitation in the case of each of them, as to the degree in which it can operate beneficially, the limitation being usually narrower and more precise, according to the elevation of the being in the scale; that an excessive supply may be destructive to the vital properties of the organism, by over-stimulating it and thus causing it to live too fast, or by more directly producing some physical or chemical change in its condition; and that a deficiency will keep-down or suspend all vital activity, leaving the structure to the unrestrained operation of those agencies which are always tending to its disintegration, and consequently occasioning a speedy loss of the vital properties,—save in those cases in which they may be preserved in a dormant condition, and which are exceptions to the general rule that the death or departure of the vital properties follows closely upon the cessation of vital actions.

44. Our fundamental idea of *Life*, then, includes that of con-

stant change or action; this change being manifested by the complete Organism in at least two sets of operations,—the continual withdrawal of certain elements from the Inorganic world,—and the incorporation of these with the peculiar structures termed Organized, or the production from them of the germs that are hereafter to accomplish this. As the *conditions* of this continual change, we recognize the necessity of an *organized structure* on the one hand; whilst we also perceive the necessity of a supply of certain kinds of matter capable of being used as the components of that structure, which may be designated as the *alimentary substances;* and, further, we see that the organism can exert no influence upon these, except with the assistance of certain dynamical agencies, such as Light, Heat, &c., that supply the *forces* or *powers* without which no change can occur. And to these forces, acting under the conditions which the Organized body alone can supply, may be attributed (as will hereafter appear) the phenomena which we distinguish as Vital.

45. A yet more characteristic peculiarity of Vital activity, however, is that presented in the *developmental* process by which the complete Organization is evolved. This process consists in a gradual *differentiation* from the simplest and most uniform type, to the most complex and highly specialized. The primordial cell which constitutes the germ of a Man, could not be distinguished by any ostensible peculiarity in its structure or composition from that of a Zoophyte; and even at a much more advanced period of its evolution it could not be distinguished from that of a Fish, Bird, or Reptile. So, again, the peculiar vital properties which in the higher animals are restricted to particular forms of tissue, such as the Muscular and Nervous, are exhibited in the lowest *Rhizopod* type (§ 199) by that sarcodic substance or protoplasm which seems to be the common basis of all organic structure; and no considerable advance is made in the evolution of the special tissues, until the general form of the organism has been marked out. It is in the degree of this process of differentiation, that the distinction lies between *high* and *low* organization; of the former we have the most striking example in the Human body, of which no two parts are exactly alike save those which repeat each other on the two sides; whilst the latter is most characteristically seen in the Rhizopods, in some of which there is not even sufficient differentiation in the protoplasmic substance to constitute a 'cell,' every particle apparently resembling every other in composition and endowments. The effect of this differentiation, in the more highly organized structures, is to bring about a 'division of labour,' by which the work of the whole organism is distributed among a number of distinct parts or 'organs,' each of them adapted to perform a certain share of it with consummate perfection, whilst their several actions are mutually dependent, and all concur in

ie general result. In the simplest organisms, on the other hand, e same endowment, as well as the same composition, are distri- ited throughout all the component particles of the fabric, which this respect approximates much more closely than do the more ghly organized fabrics to the homogeneousness of Inorganic dies. This process of *development* is in striking contrast to ything which we see in the Inorganic world; the growth of a ystal, which makes the nearest approach to it, being the result a mere symmetrical aggregation of particles of uniform character 4), whilst, in the evolution of any organism from its germ, a ntinual removal and replacement of particles becomes necessary the production of its typical and complete form.

46. And even when this form has been at last attained, a similar mbination of removal and replacement is required for the *main- iance* of the Organism in its integrity; the vital properties cha- teristic of its component tissues being only sustained by the ntinual renewal of their substance by the process of Nutrition. iese properties manifest themselves with the first complete deve- pment of the tissue; they are retained and exhibited so long as ive nutritive changes are taking place in it; their manifestation weakened or suspended if the nutritive operations be feebly erted; and they depart altogether, whenever, by the cessation those actions, and the uncompensated influence of ordinary emical forces, the structure begins to lose that normal compo- ion and arrangement of parts, which constitutes its state of *anization*. Hence we must regard these peculiar properties as ecial manifestations of those more general properties which have en previously dwelt upon as characterizing a living organized ucture; and as having their origin in the endowments of the ginal germ, which are distributed, so to speak, among the eral parts of the organism, in virtue of the special adaptation ich each acquires for a distinct purpose, the property being in- sified in proportion as it is restricted. Thus, the spongioles at extremities of the root-fibres of a tree absorb fluid with far re rapidity than does the general surface of a sea-weed; and contraction of a Human muscle is far more rapid and energetic n that of the sarcodic substance which forms the whole body a Rhizopod.

Of the Forces concerned in the Production of Vital Phenomena.

7. In prosecuting his inquiry into the *causes* of those pheno- na of living organisms, which, being of a totally different order n those of Inorganic matter, are distinguished as Vital, the ysiologist must take as his guide those methods of investigation ich have proved successful in other departments of scientific earch. If he turn, then, to the sciences of Mechanics, Optics,

Thermotics, Electricity, Magnetism, or Chemistry, he finds that the phenomena which they respectively comprise are referable to the operation of certain *forces*, and that what are termed the *laws* of those sciences are nothing else than expressions of the *conditions of action* of those forces. Thus, in Mechanics, we have principally to do with the *motion* of masses of matter, and our idea of *force* is chiefly derived from our own experience of the exertion of a *power* in producing or resisting motion; whilst the '*laws*' of Mechanics are nothing else than expressions of the conditions under which the forces or powers that produce motion operate upon matter. So in Optics, we have to do with the force which we term *light;* and the laws of Optics are expressions of the conditions under which that force is propagated, and of its action on material substances. In Thermotics, again, we have to do with the force of *Heat;* and its laws are expressions of the circumstances under which heat is propagated, and of the changes which it occasions in the substances it affects. So in the sciences of *Electricity* and *Magnetism*, we have to do with the forces known under those names; and with the laws expressive of their action upon matter. And the scientific Chemist refers all the phenomena with which he is concerned to the operations of *Chemical Affinity*, and endeavours to deduce from observation of the phenomena the laws of the operation of this force.—So the Physiologist will be justified in assuming a *Vital Force* (or *Forces*) as the power which operates in producing Vital phenomena; and will most legitimately pursue his science by inquiring into the conditions under which that force operates.

48. The analogy of the Physical Sciences may be advantageously pursued further.—Although we are accustomed to speak of the Mechanical power that produces Motion, of Light, of Heat, of Electricity, of Magnetism, and of Chemical Affinity, as *distinct forces*, yet it has gradually become apparent that very intimate relations subsist between them, and that they are, in fact, mutually convertible; so that one force (A) operating upon a certain form of matter, ceases to manifest itself, another force (B) being developed in its stead; whilst, in its turn, the second force (B) may be reconverted into the first (A), or into some other (C), which again, may reproduce either the first (A), or second (B), or some other (D or E).—It was in the case of Electricity and Magnetism that this reciprocal relation, which is designated as 'correlation,' was first clearly apprehended. If an electric current be passed round a piece of soft iron, that iron becomes magnetic, and remains so as long as the current is circulating: on the other hand, from a magnet put in motion, an electric current may be obtained. Hence we are accustomed to connect these two forces under the term Electro-Magnetism; but they can be easily shown to be quite distinct in their modes of operation on matter; and their re

tion is not really more intimate than that of other forces. For eat may be developed by Electricity; as when a galvanic current, sent through a thin platinum wire, heats it to ignition or en fuses it. Conversely, Electricity may be developed by Heat; when heat is applied to bars composed of dissimilar metals in ntact with each other. Again, if Mechanical Motion be re-rded, as in *friction*, we immediately have a development either Heat or of Electricity; heat alone being developed when the o rubbing surfaces are composed of precisely the same sub-nce; and electricity being produced when these substances are ferent. And it is for the most part through the medium of eat or Electricity, that the force of Mechanical Motion is 'cor-ated' to Light, Magnetism, and Chemical Affinity.

19. The idea of correlation also involves that of *a certain defi-e ratio*, or *relation of equivalence*, between the two forces thus tually interchangeable; so that the measure of force B, which xcited by a certain exertion of force A, shall, in its turn, give to the same measure of force A as that originally in operation. us, when an electric current is set in motion by galvanic action, have a conversion of chemical force (which has manifested lf in the decomposition of the water and the oxidation of the c) into electrical; but the electric current may, in its turn, be de to produce chemical decomposition; and the amount of this d of change which it will effect, bears a precise correspondence *teris paribus*) with the amount of zinc which has undergone dation in the galvanic cell. In like manner, when water at ° is converted into steam, the heat which it receives is no ger manifested *as* heat, but mechanical force is developed in its d, and this in a certain definite ratio, so that the 'mechanical ivalent' of heat is capable of being exactly determined: so 1, however, as the steam, losing its elasticity by condensation, urns to the condition of water, the original equivalent of heat gain developed, its mechanical force being no longer mani-ed.*

0. Now, in every case in which one force is thus converted another, the change is effected through the medium of a certain

The above statement is an expression of the simple facts of the case, which, 1 thus understood, render the hypothesis of 'latent heat' altogether un-ssary. This hypothesis, however ingenious, will doubtless share the fate any other such attempts to substitute a form of words for realities. It osed the 966 degrees of heat expended in converting a certain amount of r at 212° into steam at 212°, to become altogether *inactive* or *latent*; and no account whatever of the mechanical force which is produced in that f conversion. The idea of an *inactive force*, in fact, is one that cannot be tained; for if a force ceases to be active, it is no longer 'force.' And it ot be imagined that force, any more than matter, should cease to exist; *st* manifest itself under some other aspect.—For a complete exposition of mutual relations existing among the above-named agents, see Prof. Grove's se "On the Correlation of the Physical Forces."

form of matter, or *material substratum.* This may be, in some cases, of almost any description whatever; as when Heat is produced by the friction or retarded motion of solids, liquids, or eve gases; or when Motion (as shown in expansion) is produced b the application of heat to any kind of material substance. Bu in other cases, the change can only be effected through some *specia* form of matter; or, if several substances may serve as its mediur there is some one which is greatly superior to all the rest in th readiness with which a certain force manifests itself through i Thus *iron* is the substance through which Electricity can best b converted into Magnetism; and the development of magneti force, therefore, is most readily effected through this medium. S Heat is more readily converted into Electricity through a comb nation of bismuth and antimony, than through any other metals and the affection of Light by magnetic force (discovered a fe years since by Prof. Faraday), though producible through ar transparent substance, can be made much more obvious when tl magnetism is made to act upon a peculiar glass composed of vitr fied borate of lead, than through any other medium yet known.- This *speciality* in the action of different substances, when su jected to the same forces, is a fact of fundamental importanc and it is on it, indeed, that our notion of their several *propert* depends.

51. Now as the properties of every kind of matter require certa conditions for their manifestation, our acquaintance with the entirely depends upon whether the conditions of their action ha been afforded. Thus, to go back to a former illustration, supposi a new chemical element to be discovered, we could not know properties in regard to heat, electricity, or magnetism, the mode its combination with other elements, the nature and properties the compounds produced, their reactions with other compoun &c., until we have tried a complete series of experiments upon it that is, until we have placed it in all the circumstances or con tions requisite to manifest the properties with which we seek become acquainted, or whose absence we seek to determine if tl do not exist. Now we might have made all the experiments could devise upon such a body; and yet we might have failed detecting some remarkable and distinguishing property inheren it, simply because we had not placed it in the requisite circu stances for the manifestation of this peculiarity. Further, e in the elements or compounds with which we are best acquain it is very possible that properties exist of which we as yet kn nothing, simply because they have not yet been called into act by the requisite combination of conditions. For example, no would have thought it possible, a few years since, that water co be *frozen* in a *red-hot* metallic vessel; and yet this is now kno to be effected with ease and certainty by a proper arrangemen the circumstances.

52. Again, the properties of a compound substance are, in general t least, altogether different from those which present themselves ı either of its components; so that we could not in the least deree judge of the former from the latter, or of the latter from the ərmer. What more different, for example, than the physical and hemical properties of Water, from those of either the Oxygen or ıe Hydrogen that enter into its composition? Or what more ifferent than the properties of a neutral salt, from those of the cid and alkali by the union of which it is produced?

53. Further, the physical properties of a substance may be comletely changed by an alteration in its condition as regards Heat r any other of the forces already mentioned. For example, the articles of water have so strong an attraction for each other at a ɔw temperature, as to become aggregated in a crystalline form nd to produce a dense solid mass; at somewhat a higher temerature, their mutual attraction is so slight that a very small mount of mechanical force is sufficient to separate them, and they ıove upon each other with the utmost freedom; whilst at a still igher temperature, they manifest a power of mutual repulsion, hich increases very rapidly with every augmentation of heat. et when the temperature of the substance is lowered to its forıer standards, we observe that it first returns to the liquid, and ıen to the solid form; and that, in those states, it manifests all ıe properties which before characterised it.

54. Not merely the physical, but the chemical properties of odies may be affected by a change in their mechanical condition. hus, it is well known that oxygen and iron, at ordinary tempeatures, have a mutual affinity which is only sufficient to produce slow combination between them; whilst at high temperatures, ıat affinity is such as to cause their rapid and energetic union. Iow if iron in a state of very minute division, such as it possesses hen set-free from the state of oxide by means of hydrogen, at ıe lowest possible temperature, be brought into contact with xygen or even with atmospheric air at ordinary temperatures, it nmediately becomes red-hot and is converted into an oxide. The ıinuteness of the division, predisposing to chemical union, appears ɔ be one element in our power of causing many substances to ɔmbine, when one or both are in the *nascent* state (that is, when ıst set-free from some other combination), which could not be ıade to unite in any more direct manner; thus, when a quantity, owever minute, of any preparation of arsenic, is dissolved in uid in which hydrogen is being generated, the hydrogen will etach the metal from its previous combination, and will pass ɔrth in union with it as arseniuretted hydrogen, a compound hich cannot be formed by the direct union of the elements. In ke manner, in that mechanical mixture of three finely-divided ubstances which we call gunpowder, the rapidity with which

D

combustion is propagated through the largest collection of it, is entirely dependent upon the minute subdivision of its components, and the very close approximation of their particles. Hence it may be very correctly said that the true chemical properties of the substances are not manifested except when these are in a state of very minute division; and that they are in fact obscured by the aggregation of the particles into masses.—Thus, then, we are at no loss to discover in the Inorganic world examples of an alteration in the sensible properties, both Chemical and Physical, of the bodies composing it, by a change in the conditions in which they are placed. And it may be stated as a general fact, that we never witness the manifestation of new properties in a substance, unless it has undergone some change in its own condition, of which altered state these properties are the necessary attendants.

55. Now if we apply the same methods to the phenomena of Life, we shall see that they will lead to a mode of viewing them, which will considerably tend to the simplification of Physiological science.—In the first place, we have to look at these phenomena as the results of certain *forces*, acting through those forms of matter which we term Organized; and these forces we shall provisionally designate as Vital. Thus in the growth of the simple Vegetable cell, as already described (§§ 21—36), we trace the operation of a force closely allied to ordinary *chemical affinity*, but so far different, that it can only be exerted through a living organism; of a force of *assimilation* or vital transformation; and of a force of *organization* and complete vitalization. Now although we may provisionally designate these as distinct forces, on account of the diversity of their manifestations, it is impossible not to see that they are mutually dependent, and that they form the successive elements of a continuous series of phenomena belonging to the same category, that of *cell-life;* and further, we observe that they operate under the same conditions, namely, the presence of a cell-germ and of the materials of its growth, and the action of light and heat. Again, in the *multiplication* of the original cell, by whatever method performed, we cannot but trace the continued action of forces of the same character; since this operation takes place as a continuation of the process of growth, and under precisely the same influences. Further, we occasionally meet with examples, even among the simplest forms of Vegetation, of very active *movement;* thus the filaments or elongated cells of the *Oscillatoriæ* are continually bending themselves backwards and forwards, with a regular rhythmical undulation; and the 'zoospores' of the *Confervæ* (§ 22) are propelled through the water by the rapid vibration of the cilia with which they are furnished. Now that such a production of a purely physical change is a manifestation of vital force, is obvious from this,—that it takes place only while the vitality of the organism endures, and

hat it is dependent upon the very same conditions as the other ital operations require; and it is further interesting to remark in he case of the 'zoospore,' that it seems to take the place of the perations of growth, for these do not commence until the movement of the spore has ceased. The spiral filaments, again, which ave been discovered in most of the higher Cryptogamia, and which seem to perform the same function with the spermatozoa of nimals (§ 243), have a like spontaneous movement, which must e looked-upon as an expression of *their* vital force. Many cases f motion produced by a change of form of certain contractile ells, might be cited from among the higher tribes of the Vegeable kingdom; these movements being sometimes rhythmical and pontaneous, as in the *Hedysarum gyrans*,—sometimes taking-lace only in respondence to stimulation, as in the *Dionæa muspula* (Venus's fly-trap),—and sometimes occurring as part of ie series of ordinary vital phenomena, although producible also y stimulation, as in the *Mimosa pudica* (sensitive plant), which egularly closes its leaves at night, but will do so at any time hen they are touched or otherwise irritated. These movements ily take-place during the life of the Plant; and it is particurly observable in the last-named species, that the facility with hich they may be excited in any individual is closely related to ie activity of its vegetating processes.—Thus even in the Plant, e see that the Vital forces manifest themselves, not merely in owth, but in *movement*.

56. When we examine the structure of one of the higher Plants, e find that although the principal part of its fabric is still made-) of unmetamorphosed cells, yet certain portions of it have unrgone *histological transformation*; that is, its primordial cells ve lost their original character, having been changed into her kinds of tissue. This transformation takes-place to a much eater extent in the Animal body; in which the variety of tions to be performed is much larger, and in which we accordgly find a much greater variety of tissues developed as their struments. But however widely these tissues may depart from eir original character, we find that the process of transformation kes-place under the same conditions as that of growth, and must regarded as a continuation of it; being, in fact, the special manitation of vital force in one set of cells, as multiplication is in other, or as motion in another. And we shall find, that, in prortion as this specialization takes place, do the tissues lose their re general vital endowments.

57. Hence, then, we have reason to believe that all the truly *tal* phenomena, however diversified, are but results of the operan of one and the same Force, whose particular manifestations determined by the nature of the material substratum through ich it acts; the same fundamental agency producing simple

growth in one case, *transformation* in another, *multiplication* in a third, *mechanical movement* in a fourth, whilst in a fifth it developes *nervous power*, which may itself operate in a variety of different modes. Such a view seems fully justified by the consideration, (1) that all these forces are manifested in connection with each other, as parts of the life of each individual cell, in those simple organisms which are the lowest members of the two kingdoms respectively, and in which there is no separation or specialization of function; (2) that they may be exerted, even in the most highly-organized living being, through a common instrumentality, the simple cell; and (3) that the entire assemblage of tissues making-up the totality of any organism, have all a common parentage, being lineally descended from the single primordial cell in which it originated.

58. The question next arises,—what is the source of the Vital Force of which the phenomena of Life are the manifestations? The prevalent opinion has until lately been, that there is a power or energy inherent in the germ, which derives from its parent not merely its material substance, but a *nisus formativus* or 'germ-force'; in virtue of which it builds itself up into the likeness of its parent, and maintains itself in that likeness until the force is exhausted, at the same time imparting a fraction of it to each of its progeny. In this mode of viewing the subject, all the organizing force required to build up an Oak or a Palm, an Elephant or a Whale, must be concentrated in a minute particle only discernible by microscopic aid; and the aggregate of all the germ-forces appertaining to the descendants, however numerous, of a common parentage, must have existed in their original progenitors. Thus in the case of the successive viviparous broods of *Aphides* (plant-lice), a germ-force capable of organizing a mass of living structure calculated to amount in the tenth brood to the bulk of 500 millions of stout men, must have been shut up in the single individual, weighing perhaps the 1-1000th of a grain, from which the first brood was evolved. When we carefully look into the question, we find that what the germ really supplies is not the *energy* or working power, but the *directive* agency; this rather resembling the control exercised by the superintendent builder who is charged with working-out the design of the architect, than the bodily force of the workmen who labour under his guidance in the construction of the fabric.

59. The energy or power which really does the work must therefore be sought externally to the Organism; and under the guidance of the ideas derived from Physical Science, we shall have no difficulty in finding it in the operation of certain Forces, the influence of which has long been known to be essential to Vital action, and which have been usually designated by the term *Vital Stimuli.* Thus, the growing Vegetable cell cannot decompose

arbonic acid except when acted-upon by *Light;* and the amount f this change which it effects is in strict ratio (*cœteris paribus*) rith the illuminating power of the rays which it receives (§ 86). So, again, neither Plants nor Animals can maintain their activity xcept under the continual influence of a certain measure of *Heat;* nd the amount of that activity will be shown to bear a constant atio, in all those tribes which have no independent power of susaining it, to the quantity which they receive from external sources CHAP. II. Sect. 2); this being true, not merely of the general ate of the Vegetative actions of growth and development, but lso of those manifestations of vital power which are peculiar to nimals. Thus we may say that Light and Heat acting upon the)rganic germ, become transformed into Vital force, in the same ıanner as Heat acting upon a certain combination of metals beomes Electricity, or as Electricity acting upon iron developes itself s Magnetism: and we shall find that this view is in complete armony with all the phenomena of Vital action. Moreover, the ital force thus engendered frequently manifests itself in producing 'hysical or Chemical phenomena; thus completing that *mutual* elationship, or correlation, which has been shown to exist among he Physical and Chemical forces themselves (§§ 48, 49). Of this re have already seen an instance, in the *movements* produced by ıuscular contraction and by ciliary vibration. The production of *eat* by certain Plants and by warm-blooded Animals, is another pposite exemplification of the same principle. But the most reıarkable illustration is undoubtedly derived from the Nerve-force; rhich, whilst itself a peculiar form of the general Vital force, and apable of affecting all the other manifestations of the same force as in the modifications which it produces in the processes of Nuition and Secretion, as well as in exciting Muscular Contraction), s capable of developing Electricity as well as Light and Heat, nd is also capable of being called-forth by the action of Light, Ieat, Electricity, Chemical Affinity, or even Mechanical Motion, n the Nervous tissue. It is a most remarkable confirmation of he views here advanced, that the Nerve-force, which must be ccounted, in its relation to Mind, as the highest of all the forms f Vital force, should yet be the one which is most directly and ıtimately related to the Physical forces,—the 'correlation' even f Electricity and Magnetism not being more complete, that the correlation' of Electricity and Nerve-force may be shown to be) 396).

60. Thus, then, not only are the *materials* drawn from the Inoranic world by vital agencies, given-back to it again by the disinegration of the living structures of which they form a part; but ll the *forces* which are operative in producing the phenomena of ife, being first derived from the Inorganic universe, are returned o it again under some form or other. The Plant forms those

organic compounds, at the expense of which Animal life (as well as its own) is sustained, by the decomposition of carbonic acid, water, and ammonia; and the *light*, by whose agency alone this process can be effected, may be considered as metamorphosed into the peculiar *affinity* by which the elements of these compounds are held together. The *heat* which Plants receive, acting through their organized structures as Vital force, serves to augment these structures to an almost unlimited extent, and thus to supply new instruments for the agency of light and for the production of organic compounds. The whole *nisus* of Vegetable life may be considered as manifested in this production; and, in effecting it, each organism is not only drawing *material*, but *force*, from the universe around it. Supposing that no Animals existed to consume these organic compounds, they would be all at last restored to the inorganic condition by spontaneous decay, which would reproduce the carbonic acid, water, and ammonia, from which they were generated. In this decay, however slow, heat and light are given out in the same amount as when more evidently produced in the ordinary combustive process; and this sometimes occurs even during the life of the plant, whose vital movements, also, may be considered as restoring to the Inorganic universe a certain measure of the force derived from it under other forms. So, in making use of the stores of Coal which have been prepared for his wants by the luxuriant Flora of past ages, Man is not only restoring to the atmosphere the carbonic acid, the water, and the ammonia, of the Carboniferous period; but is actually reproducing, and applying to his own purposes, the Light and Heat which were operating to produce the growth of vegetation at that remote period in the Earth's history.

61. But the organic compounds which the agency of Light and Heat upon the Vegetable structures has produced, are designed for a much higher purpose than that of being merely given back to the Inorganic universe by decay or combustion; and the forces which hold together their elements have a much more exalted destiny. In serving as the food of Animals, a part of them become the materials of *their* organized tissues, and the instruments through which the nervous and muscular forces are developed; whilst another part are applied to sustain the combustive process, by which the heat of the higher Animals is maintained quite independently of the external supply of that force. The greater part of the Animal kingdom, however, is dependent, like the Vegetable, upon the Inorganic Universe, for the Heat which serves as its organizing force; and it is only under the constant influence of this agent, that the operations of growth, development, and maintenance can take place. The Animal is not dependent like the Plant upon Light; and this is obviously because this agent is chiefly concerned in that preliminary operation by which the organic compounds are

generated as the pabulum of the growing tissues; in fact, the embryo within the germinating seed, which, like the animal, is nourished upon matter previously prepared for it, is most rapidly developed in the absence of light, up to the time when, this store being exhausted, its further supplies must be obtained by its own instrumentality.

62. The Vital activity of Animals, then, may be considered as chiefly sustained by the Chemical forces subsisting in their food, which are set-free when the elements are reconverted to their original state; and by the Heat which they derive from external sources, or from the combustion of a part of their food. These forces may be considered as in a state of continual restoration to the Inorganic Universe, during the whole life of Animals, in the heat, light, electricity, still more in the motion, which they develope; and, after their death, in the production of heat and light during the processes of decay. During Animal life, there is a continual restoration to the mineral world, of the carbonic acid, water, and ammonia, which have been appropriated by Plants; and it will hereafter appear that the amount thus given-off by the animal organism bears a close correspondence, on the one hand, with its degree of vital activity, as shown in the amount of heat and motion which it generates, and, on the other, with the amount of the organic compounds which it consumes as food. So that, on the whole, there is strong reason to believe that the entire amount of force (as of material) received by an animal during a given period, is given-back by it during that period, provided that its condition at the end of the term be the same as it was at first; and further, that all the force (like the material) which has been expended in the building-up of the organism, is given back by its decay after death.*

4. *Of Degeneration and Death.*

63. As we have no evidence of the existence of Vital properties in any other form of matter than that which we call Organized, so have we no reason to believe that organized matter can retain its normal constitution, and be subjected to the appropriate forces, without exhibiting vital actions. The advance of Pathological science renders it every day more probable (indeed the probability may now be said to amount to almost positive certainty) that derangement in *function*,—in other words, an imperfect or irregular *action*,—always results from some change of structure or composition, either in the tissue itself, or in the blood which permeates it, unless it can be traced to a change in the forces by which the

* The whole of this subject is more fully developed in the Author's Memoir on "The Mutual Relations of the Vital and Physical Forces," contained in the Philosophical Transactions for 1850.

properties of the organ are called into action. A degenerative change takes place in Nerve-fibre in the course even of a few days, when its continuity with the Nervous centres has been interrupted by section; so that it becomes incapable of transmitting nerve-force, although appearing unchanged to the unaided eye. On the other hand, irregular and violent action of certain muscles (as in some forms of Cramp) may be a consequence of the presence of noxious matters in the blood which circulates through them; or, again, it may be due (as in Convulsive disorders generally) to irregular stimulation received from the Nervous system; and the functional derangement of the last-named apparatus may be either due to the presence of some toxic substance in the blood, or may arise from some mechanical injury in a distant part.

64. As there is a constant tendency, in the Animal tissues more especially, to spontaneous decay, so must the maintenance of their vital properties depend upon their continual regeneration by the nutritive operations. Hence we have no difficulty in accounting for the Death of the whole system, on the cessation or serious disturbance of any one important function; for any such check or change must suspend or disorder the nutrient processes, in such a degree that they can no longer maintain the normal constitution of the several tissues. But as there is a great variety in the rapidity of the decomposition of the tissues when the act of nutrition is suspended, so do we witness a corresponding variety in the duration of their vital properties, after that permanent severance of the chain of functions which is distinguished as *somatic* death,—*i. e.*, the death of the *body* as a whole. It is by the Circulation of the Blood that the connection of the different functions is essentially maintained; that fluid not only supplying the material for the nutrition of the tissues, but in many cases affording also the stimulus to their activity. Hence with the permanent cessation of the Circulation, *somatic* death must be regarded as taking place.

65. Yet after this we observe that vitality lingers in the tissues, and that it departs from them only as they lose their proper composition. Thus we find that although the Nervous *centres* cannot *originate* the stimulus necessary to produce Muscular contraction after the Circulation has ceased, yet the nervous *fibres* can *convey* such a stimulus long after somatic death; so that contractions may be excited in muscles by the application of galvanism, or of mechanical or chemical stimulants, to the trunks that supply them. The *molecular* death of the Nervous tissue, therefore, has not yet taken place. After a time, however, this power is lost; the tissue no longer exhibits its distinguishing vital properties; and incipient decomposition and change of structure manifest themselves. Yet for some time after this, the Muscular tissue, especially in a cold-blooded animal, continues to possess its peculiar contractility; for contractions may be excited in it by stimuli directly applied to

itself, long after the nerves have ceased to convey their influence. Sometimes, indeed, the contractility of muscle endures, until changes in its structure and composition become evident to the senses; thus the heart of a Sturgeon, removed from the body, and hung up to dry, has been known to continue alternately contracting and dilating until the movement produced a crackling noise in consequence of the dryness of the texture. Again, there is evidence that various processes of nutrition and secretion may go on for some time after somatic death, and even after the removal of the organs from the body, provided that a sufficient quantity of blood remain in them; and the blood itself retains its vitality, so as not to coagulate, whilst contained in the vessels of tissues still living.

66. Hence it is that parts which have been *completely* separated from the body may often be reunited with it, if they were previously in a healthy state and too much time have not elapsed; thus there are many cases on record, in which fingers, toes, noses, or ears, that have been accidentally chopped-off, have been made to adhere and grow as before by bringing the cut surfaces into contact, even some hours after their severance. It is evident, then, that the parts so severed cannot have lost their vitality; since no treatment could produce union between a dead mass and a living body. And we are fully justified in assuming, that, in cases where attempts at such reunion have not been successful, the death of the separated part has resulted from the too-prolonged interruption of its regular nutritive operations, whereby such chemical and physical changes have taken-place in it, as have destroyed the peculiar structure and composition of its several parts.—The ordinary phenomena of Death, therefore, as well as those of Life, bear out the views which have been here advanced.

67. But it has been maintained by those who consider Vitality as something superadded to an Organized Structure, essentially independent of it, and capable of being subtracted from it, that Death frequently takes place under circumstances which leave the organism as it was; so that "the dead body may have all the organization it ever had whilst alive." For such an assumption there is not the least foundation. In nearly all cases in which death takes-place as a result of disease, the connection between changes of structure and composition, either in the tissues or in the blood, and such a loss of the vital properties of some part or organ as is sufficient to bring the Circulation to a stand, is so palpable as to require no proof; and in by far the greater majority of cases in which it is not at once obvious, a more careful scrutiny will reveal it. It must be confessed on both sides, that our means of investigation, and our knowledge of the normal structure and composition of the tissues and the blood, are not yet sufficient to enable us to detect minute shades of alteration, nor to assert what

extent of change is inconsistent with the continuance of life. But as no one has yet shown, by the careful and exact microscopical and chemical examination of the solids and fluids of a dead body, that it has all the organization it had whilst alive, the assertion above quoted is totally unwarranted by experience, and is contradicted by all our positive knowledge of the matter.

68. But it has been urged, that Death may result from the sudden operation of some agency of an *immaterial* character, which leaves no trace behind it,—such as a powerful electric shock, or a violent mental emotion. Here, too, the argument entirely fails. It is *impossible* that a powerful electric shock could be transmitted through a mass like the animal body, composed of elements in such a loose state of combination that they are always undergoing decomposition, without producing important *chemical* changes in it; and its imperfect conducting power renders it equally liable to *physical* disturbances. As a matter of fact it has been noticed, that the bodies of animals killed by electricity pass into decomposition with unusual rapidity, showing that the ordinary chemical affinities of their components have received a powerful stimulus; and it has also been ascertained, that when eggs in process of development have had their vitality destroyed by an Electric shock, the minute vessels of the *vascular area* (§ 551) have been ruptured.—Nor is it more difficult to explain the immediate cause of death, as a result of Mental emotion. In some cases, an obvious physical change has been produced by the too violent action of the heart, the movements of which are stimulated by the emotion; thus, even in a healthy person, rupture of the heart or aorta has been known to take place,—an occurrence to which those affected by previous disease of that organ are much more liable. Where there is *any* disorder in the heart's action, resulting from thickened valves, narrowed orifices, &c., the physical influence of mental emotion can be easily accounted-for. But it must be admitted that cases have occurred, in which no such explanation can be offered; sudden death having taken place without any perceptible structural cause. We are not obliged, however, for an explanation of even these cases, to have recourse to any hypothesis which is not borne-out by ample analogy. For it is well known that mental emotions, acting through the nervous force, exert a powerful influence over the composition of the *fluids* of the body, and are capable of *instantaneously* altering these. Thus, in many human beings, and still more in the lower animals, alarm or agitation will occasion the immediate disengagement of powerfully-odorous secretions, which must have resulted from new combinations suddenly formed; and a fit of passion may immediately occasion such a change in the milk of a nurse, as renders it a rank poison to the infant. There is no reason to doubt, therefore, that the blood itself may undergo changes of analogous character from the same

cause, and that it may become a violent poison to the individual himself, instead of being the source of wholesome nutriment and the stimulus to vital activity.

69. But the effect of Electricity, of Mental Emotion, or even of Mechanical force, may be exerted more *dynamically* than organically; suppressing all Vital activity, by antagonizing the forces that sustain it, without occasioning any perceptible *material* change. This, in fact, we see in the state of prostration or 'shock,' induced by sudden and violent impressions of almost any description, especially those which have a direct influence upon the Nervous System; such as concussion of the brain, blows upon the epigastrium (producing concussion of the solar plexus), rupture of any important viscus, and the like. Such agencies are found to exert a remarkable influence, not only upon the actions of the Heart (which they affect through the nervous system), but also upon the vital powers of the tissues generally; these being found to depart more speedily than they do when the circulation is suddenly brought to a stand by other means.

5. *General Summary.*

70. To conclude, then;—we only know of *Life*, as exhibited by an Organized structure, when subjected to the operation of certain *forces* which call it into activity; and we only know of *Vitality*, or the state or endowment of the being which exhibits that action, as conjoined with that particular aggregation and composition which we term *Organization.* We have seen that the act of Organization, and the consequent development of peculiar properties in the tissues which are produced by it, can only be attributed to the vital force of a pre-existing organism; and hence it is, that whilst the operation of Physical forces upon an Organized body gives rise to Vital phenomena, no such phenomena can be manifested as the result of their action upon any kind of Inorganic matter. It is, in fact, the *speciality* of the material instrument thus furnishing the medium of the change in their *modus operandi*, which establishes, and must ever maintain, a well-marked boundary-line between the Physical and the Vital forces. According to the views here propounded, the Vital force is as different from Heat or Electricity, as these are from each other; but just as Heat, acting under certain peculiar conditions, is capable of transformation into Electricity, whilst Electricity is capable, under certain other conditions, of being metamorphosed into Heat, so may either of these forces, acting under conditions which an Organized fabric alone can supply, be converted into Vital force, whilst, in their turn, they may be generated by Vital force.

71. Starting, then, with the abstract notion of one general Force, we might say that this Power, operating through Inorganic

matter, manifests itself in those phenomena which we call electrical, magnetical, chemical, thermical, optical, or mechanical; the agents immediately concerned in these being so connected by the relation of reciprocal agency, or 'correlation,' that we must regard them as fundamentally the same. But the very same Force or Power, when directed through Organized structures, effects the operations of growth, development, metamorphosis, and the like; and is further transformed, through the instrumentality of the structures thus generated, into nervous agency and muscular power. If we only knew of Heat, for example, as it acts upon the Organized creation, the peculiarities of its operation upon Inorganic matter would seem no less strange to the Physiologist, than the effects here attributed to it may appear to those who are only accustomed to contemplate the Physical phenomena to which it gives rise.—Of the existence of Force or Power, we can give no other account than by referring it, as we are led by our own consciousness to do, to the exertion of a Will; and this unity among the Forces of Nature is the strongest possible indication of the Unity of the Will of which they are the expressions. And further, the constancy of the actions which result from them, when the conditions are the same,—that is, their conformity to a fixed plan, or (in the language commonly employed) their subordination to *laws*,—indicates the constancy and unchangeableness of the Divine Will, as well as the Infinity of that Wisdom by which the plan was at first arranged with such perfection, as to require no departure from it in order to produce the most complete harmony in its results.

72. So also, if we endeavour to assign a cause for the existence of a cell-germ, we are led at first to fix upon the vital operations of the parental organism by which it was produced; and for these we can assign no other cause than the peculiar endowments of *its* original germ, brought into activity by the forces which have operated upon it. Thus we are obliged to go backwards in idea from one generation to another; and when at last brought to a stand by the origin of the race, we are obliged to rest in the Divine Will as the source of those wonderful properties, by which the first germ developed the first organism of that race from materials previously unorganized, this organism producing a second germ, the second germ a second organism, and so on without limit, by the uniform repetition of the same processes. Yet we are not to suppose that the *continuation* of the race is really in any way less dependent upon the Will of the Creator, than the *origin* of it. For whilst Science leads us to discard the idea that the Deity is continually *interfering*, to change the working of the system He has made,—since it everywhere presents us with the idea of uniformity in the plan, and of constancy in the execution of it,—it equally discourages the notion entertained by some, that the

creation of matter, endowed with certain properties, and therefore subject to certain actions, was the *final* act of the Deity as far as the present system of things is concerned, instead of being the *mere commencement* of His operations. If it be admitted, that matter owes its origin and properties to the Deity, or, in other words, that its *first existence* was but an expression of the Divine Will, what is its *continual existence*, but a continued operation of the same Will? To suppose that it could continue to exist, and to perform its various actions, *by itself*, is at once to assume the propertyof *self-existence* as belonging to matter, and thus to do away with the necessity of a Creator altogether;—a conclusion at which it may be safely affirmed, that no ordinarily-constituted Man can arrive, who reasons upon the indications of Mind in the phenomena of Nature, in the same way as he does in regard to the creations of Human Art.

CHAPTER II.

OF THE EXTERNAL CONDITIONS OF VITAL ACTIVITY.

73. It has been shown in the preceding Chapter, that the most general conditions of Vital phenomena are two-fold; — one set being supplied by the *organized structure*, which is endowed (in virtue of its organization) with certain peculiar properties, but which is inert so long as it is altogether secluded from the influence of external agents; — whilst the other is derived from external sources, and consists in a supply of those *materials* of which the organized structure is built up, and in the operation of those *forces* by which the organism is made to appropriate those materials which are the sources of its peculiar powers. We might thus, in a rough and rude way, it is true, compare the living body to a set of machinery adapted to convert cotton from the raw material into a woven fabric. Each portion of the machinery does its own special work, in virtue of its peculiar construction; *e.g.*, one part cards, another spins, and a third weaves; but their actions are closely related and even mutually dependent. Further, their operations all result fpom one and the same Force or Power; and their products may consequently be regarded as the expressions or manifestations of that Force, which acts through the different portions of the mechanism, each in its own peculiar mode. Now such a machine can produce no result, without the concurrence of these conditions; namely, the perfectly-constructed *organism* (for

so in the wide sense of the term it may be designated), a supply of the raw *material* on which it is to operate, and an adequate *moving power*. And it is to be observed, that the amount of its product will depend rather upon the *power*, than upon the *material* supplied; for whilst its activity cannot be increased by any augmentation in the quantity of the material beyond that amount which it has power to employ, it can be promoted by a more energetic application of the force, as well as retarded by its diminution; the amount of material appropriated being increased or diminished accordingly.

74. In like manner, it is requisite to distinguish, among the external conditions whose concurrence is necessary to produce a Living Organism, between those which furnish the *materials* requisite for its construction and maintenance, and the *forces* or powers on which its operations are dependent; in other words, between the *Material* and *Dynamical* conditions of Vital Activity.—Under the former group must be comprised, not merely the Alimentary substances which are capable of being converted into portions of the solid fabric, but also those which are used (among the warm-blooded animals) for the maintenance of the bodily heat by the combustive process. In addition, we have to include the Water which is requisite to maintain the due proportion of liquid in the organized fabric; and the Oxygen, whose presence in the surrounding medium is essential in various modes to the maintenance of its vital activity. The dependence of Vital Activity upon Food and Oxygen will be fully considered hereafter (CHAPS. V. and IX.); and in the present Chapter it will be only necessary to take account of the demand for Moisture (Sect. 4).

75. The Forces to whose operation we can most clearly trace the phenomena of Life, are *Light* and *Heat;* of which the latter is the one whose agency is the most universal, and most immediately connected with the acts of growth and development. The agency of *Light* is indispensable for the first production of organic compounds by the instrumentality of the Vegetable fabric; but it would possess no efficacy whatever, without the simultaneous operation of Heat; and when these compounds have been generated, we find that they can be applied to the purposes of Vegetable nutrition, no less than to the nutrition of Animals, without the aid of Light; as is seen in the fact that the germination of seeds takes place in darkness, and that the formation of new wood in a stem takes place beneath a thick covering of bark. A very large proportion of the vital operations of Animals have no direct dependence upon Light; yet it is entirely through its operation upon Plants, that they derive the materials of their nutriment; so that Lavoisier was fully justified in the assertion, that "without Light, nature were without life and without soul; and a beneficent God, in shedding light over creation, strewed the surface of the earth

with organization, with sensation, and with thought." As an example of the very direct relation which subsists between the amount of Light and Heat acting on an organism, and the amount of vital change produced, it may be well to advert to the statement of Boussingault, that the same annual plant, in arriving at its full development, and going through the process of flowering and of the maturation of its seed, everywhere requires the same amount of Light and Heat, whether it be grown at the equator or in the temperate zone, the whole *time* occupied being *inversely* to the intensity of these forces, and the *rate of growth* having a relation of *direct* equivalence to it.—We have little certain knowledge of the degree of the ordinary dependence of Vital Activity upon *Electricity;* although there can be no doubt that it is capable of exerting a most important influence upon the living organism.

76. In regard to all these Forces it may be observed, that the dependence of Vital Action upon their *constant* influence is greater in proportion to the complexity of their structure, and *vice versâ;* so that beings of simple organization are capable of enduring a deprivation of them, which would be fatal to those higher in the scale. This will be partly understood, when it is borne in mind that the higher the development of the living being, the more complete is the distribution of its different actions amongst separate organs,—the more intimate, therefore, is their mutual dependence,—and the more readily, in consequence, are they all brought to a close by the interruption of any one. But there is no doubt that the actions of even the individual parts of the higher organisms require for their excitement a greater supply of these powers, than the similar actions of the corresponding parts in the lower: whilst, if these forces be exerted upon the lower with the intensity that is required for the higher, they destroy the vital properties of the tissues altogether, by the excess of their action. This distinction is most obvious in regard to the relative influence of Heat upon warm-blooded and cold-blooded animals respectively; of which examples will be given hereafter.

77. It may also be observed of the influence of these, as of that of other forces whose agency is less general, that it is rather *relative* than *absolute;* being frequently dependent upon the degree of *change*, rather than upon the measure of the actual *amount*. This constitutes a marked difference between the influence of these forces on mere chemical compounds, and their operation on bodies endowed with vitality. In the former case, their action is always uniform; thus the same amount of heat, the same exposure to light, the same charge of electricity, would be required to produce a given Chemical effect, how often soever the action might be repeated. But this is not the case with living bodies; since an increase or diminution in the intensity of Heat, which, if made *suddenly*, would be scarcely compatible with the continuance of

Life, may be so brought about, as to produce no marked chan in its phenomena,—the organism possessing a certain power adapting itself to conditions which are habitual to it, and th allowing great changes in these conditions to be *gradually* effect without any serious disturbance.—Thus of two individuals of t same species, one may become torpid at a temperature of 6 because it has been accustomed to a temperature of 70°; whi another, habituated to a temperature of 60°, would require to cooled down to 50°, in order to induce torpidity; the influence temperature upon the vital condition being proportioned, more the variation from the usual standard, than to the actual deg of heat or cold in operation. Yet the first of these individu might be gradually habituated to live in the same temperat with the second; and to require the same amount of further pression for the induction of torpidity. (See § 132).

78. It is a very curious fact, that, whilst the lower classes living beings are more capable than the higher of bearing the privation of these Vital stimuli, they are at the same time m liable to alterations in their own structure and development, consequence of variations in the intensity of their agency, or fr other causes external to themselves. Thus the *forms* of the lov tribes of Plants and Animals are liable to be greatly affected by conditions under which they grow; and these especially mod their degree of development. It seems as if the formative pov were less vigorous in the lower, than in the higher classes; that the mode in which it manifests itself in the former is m dependent upon external influences; whilst in the latter it eit prodominates over them, causing the regular actions to be p formed, or gives-way altogether.—The same principle applies the early conditions of the higher organisms; their embryos, l those beings of permanently low type which they resemble degree of development, being liable to be affected by modify influences which the perfect beings of the same kind are able resist.

1. *Of Light, as a Condition of Vital Activity.*

79. The importance of this agent, not only to the Vegetable l also to the Animal World, is not in general sufficiently estimat Under its influence alone can that first process be accomplished, which Inorganic matter is transformed into an Organic compou adapted by its nature and properties to form part of the organi fabric. The following is an example of the simplest phenomer of this kind; and it demonstrates the influence of Light the m clearly on account of that simplicity. 'If we expose some spri water to the sunshine, though it may have been clear and tra parent at first, it presently begins to assume a greenish tint; a after a while, flocks of green matter collect on the sides of t

vessel in which it is contained. On these flocks, whenever the sun is shining, bubbles of gas may be seen, which, if collected, prove to be a mixture of oxygen and nitrogen, the proportion of the two being variable. Meanwhile the green matter rapidly grows; its new parts, as they are developed, being all day long covered with air-bells, which disappear as soon as the sun has set. If these observations be made upon a stream of water, the current of which runs slowly, it will be discovered that the green matter serves as food for thousands of aquatic Insects, which make their habitations in it. These insects are endowed with powers of rapid locomotion, and possess a highly-organized structure; in their turn they fall a prey to the Fishes which frequent such streams." * Such is the general succession of nutritive actions in the Organized Creation. The highest Animal is either directly dependent upon the Vegetable Kingdom for the materials of its fabric, or it is furnished with these by some other Animal, this again (it may be) by another, and so on; the last in the series being *always* necessitated to find its support in the Vegetable kingdom, since the Animal does not possess the power of causing the Inorganic elements to unite into even the simplest Organic compound. This power is possessed in a high degree by Plants; but it can only be exercised under the influence of *Light*.—We shall now examine, more in detail, the conditions of this influence, both in the instance just quoted, and in others drawn from the actions of higher Vegetable organisms.

80. The "green matter of Priestley" (as it is commonly called), which makes its appearance when water of average purity is submitted to the action of the Sun's rays, and which also presents itself on the surface of walls and rocks that are constantly kept damp, is now known by Botanists to consist of *cells* in various stages of development; some of them constituting simple forms of vegetation which are complete in themselves, whilst others are the early states of plants somewhat more elevated in the scale (§ 779). That these cells all originate from definite germs, and not in a mere combination of inorganic elements, appears not only from general considerations, but also from the fact that, if measures be taken to free the water entirely from any possible infusion of organic matter, and to admit into contact with it such air alone as has undergone a similar purification, no green flocks make their appearance even under the prolonged influence of the strongest sunlight. We find, then, that the presence of a germ is one of the conditions indispensable to the chemical transformation in question (§ 39).

81. Although a certain moderate amount of heat is undoubtedly necessary for this developmental change, yet no degree

* Prof. Draper, on the Forces which produce the Organization of Plants; p. 15.

of heat without *light* will be effectual in producing it, as is easily proved by exposing the water to warmth in a dark place. Moreover, when a certain measure of light is afforded, variations in the amount of heat make very little difference; whilst under the same degree of heat, the amount of the change is directly proportional to the intensity of the light. Although, therefore, heat furnishes an essential condition, it cannot be questioned that *light* is the chief agent in the process by which the Vegetable germ brings into union the elements to be employed in the development of its own fabric. The effect appears to be due, however, rather to these *actinic* rays of the Solar spectrum which operate in producing Photographic effects, than upon those which produce the strongest impression of *luminosity.* That growing vegetation uses up (so to speak) the actinic rays, is readily shewn by the simple experiment of placing a fresh leaf, sufficiently translucent to allow a good deal of light to pass through it, upon a piece of photographic paper, and exposing it for a time to ordinary daylight; for it will then be found that the part of the paper covered by the leaf has received scarcely any impression, the substance of the leaf having almost entirely absorbed the chemical or actinic rays, although it was by no means impervious to the luminous rays of the spectrum. And this seems to be the explanation of the fact well known to Photographers, that actively-growing vegetation generally appears dark in a photographic picture; the leafy surfaces absorbing the chemical rays, as ordinary black surfaces absorb the luminous rays. The best photographic effects are obtained from evergreen trees, whose leaves have a comparatively feeble activity; and from ordinary deciduous trees at the latter part of the summer, when the deoxidizing process by which carbon is extracted from the atmosphere has nearly or altogether ceased.

82. The materials at the expense of which the flocculent Vegetation just described developes itself under the influence of the Actinic rays, are the gases absorbed from the atmosphere by all water that is freely exposed to it. These gases, however, do not enter the liquid in the proportions in which they are contained in the atmosphere itself; their relative qualities, in a given measure of water, being proportional to the facility with which they are respectively absorbed,—Carbonic acid being most readily absorbable, Oxygen next, and Nitrogen least so. From the experiments of Prof. Draper it would appear, that, notwithstanding the very small proportion of carbonic acid contained in the atmosphere (usually not more than 1-5000th part), it forms as much as 29 per cent. of the whole amount of air expelled from water by boiling. Of the residue, one-third consists of oxygen, and the remaining two-thirds of nitrogen; so that the proportion of the oxygen to the nitrogen is as *one* to *two*, instead of being *one* to *four*, as

in atmospheric air. The absolute quantity of this water-gas, contained in any measure of water, is subject to variation with the temperature; the quantity being diminished as the temperature rises.—Now when water thus impregnated with carbonic acid, oxygen, and nitrogen, and containing the germs of aquatic plants, is exposed to the sun's light, a development of vegetable structure takes place, indicated by the green flocculent appearance noticed already. If the changes now occurring in the water be investigated, we find that the carbonic acid is diminishing in amount; and that oxygen is being evolved. The growing mass increases in volume and weight; and after a time exhausts the whole carbonic acid orginally contained in the water. If it be then prevented from receiving an additional supply, the process stops; but, as conducted naturally, there is a free exposure to the atmosphere, through which carbonic acid is diffused; and hence, as fast as this gas is removed by decomposition, it is restored by absorption.—The same holds good, also, with regard to the ammonia of the atmosphere, which, notwithstanding its very minute proportion, supplies the nitrogen required for the production of the azotised compounds of plants.

83. Here then are the conditions and materials; what is the result? By the conjoint action of light and of a vegetable cell-germ, with a moderate degree of heat, upon carbonic acid, ammonia, and water, those principal components of the vegetable fabric are produced, which consist of carbon united with the elements of water. Whether this union is really as simple and direct as is implied by this expression, or whether the same proportions of oxygen, hydrogen, and carbon are united in a different form, is not a matter of consequence to the present inquiry; the general fact being, that by the decomposition of the carbonic acid, oxygen is set-free, and carbon is made to unite with the elements of water; so as to form organic compounds, which are appropriated by the Vegetable organism as materials for its growth.—How far Light is also concerned in the production of the albuminous compounds which are generated by Plants, not merely for the use of Animals, but also as part of the material of their own growth, has not yet been ascertained; but it is probable that these are not the less dependent upon its agency for their formation, since they are generated under the same circumstances with the preceding.

84. The process whose conditions we have thus examined, is carried-on in the individual cells of which the highest and most complex Plants are composed, precisely as in those which constitute the entire organisms of the lowest. Thus, if a few garden-seeds of any kind be sown in a flower-pot, and be caused to germinate in a dark room, it will soon be perceived that although they can grow for a time without the influence of Light, that time is limited; the *weight* of their solid contents diminishes, although their *bulk*

may increase by the absorption of water; their young leaves, if any should be put-forth, are of a yellow or gray-white colour, and they soon fade-away and die. But if these plants are brought out sufficiently soon into the bright sunlight, they speedily begin to turn green; they unfold their leaves, and evolve their different parts in a natural way; and the proportion of their solid contents goes on increasing from day to day. If the fabric be then subjected to chemical analysis, it is found to contain oxygen, hydrogen, carbon, and nitrogen, united in various proportions, so as to form compounds that differ in the various species; though some,—such as gum, starch, cellulose, and albuminous matter,—are the same in all. If the plants be made to grow in closed glass vessels, under such circumstances that an examination can be accurately made as to the changes they are impressing on the atmosphere, it is discovered that they are constantly decomposing its carbonic acid,—appropriating its carbon, and setting free its oxygen,—so long as they are exposed to the influence of sunshine or bright daylight. They also appropriate a part of the minute quantity of ammonia which is diffused through the atmosphere; extracting its nitrogen to employ it in the production of their azotized compounds. It is capable of being demonstrated by experiment, that these changes are confined to the *green* surfaces of plants,* and therefore to the leaves or leaf-like organs, to the young shoots, and to the stems of herbaceous plants, or of those in which (as in the Cactus tribe) the leaves are wanting and the enlarged succulent stem supplies their place. When these surfaces cease to become green, the decomposing action also ceases; carbon is no longer fixed and oxygen set-free; but, on the contrary, carbonic acid is exhaled: this is the case when the leaves change colour, previously to their fall, in the autumn. The compounds which are thus generated in the green surfaces, are conveyed, by the circulation of the sap, to the remote parts of the fabric, and become the materials of their nutrition; and thus the green cells of the leaves have exactly the same function in ministering to the growth of the largest tree, which the green cells of the humble Protophyte perform in regard to themselves alone.

85. It has been already mentioned (§ 35) that the decay which is always taking-place in the softer Vegetable structures, gives-rise to a continual production of carbonic acid, even in the living plant; this process, which must be regarded as a true Respiration, is effected, as in Animals, by the union of the carbon of the Plant with oxygen derived from the atmosphere; and it is carried-on, not by the green parts only, but also, perhaps chiefly, by the darker surfaces. Being antagonized during the day by the converse

* There is an exception as to certain Plants, such as the Copper Beech, in which the ordinary green matter is replaced throughout by a substance related to it chemically, but having a very different hue.

hange just described, it can only be made sensible by placing the lants for a time in an atmosphere in which no carbonic acid pre-iously existed; and it will then be found that, even in full day-ght, a certain amount of that gas is exhaled. The fact, however, ecomes much more obvious at night, or in darkness; since the ecomposition of the surrounding carbonic acid by the green urfaces is then completely at a stand, and the full effect of the espiratory process is seen. Moreover, when a plant becomes nhealthy from too long confinement in a limited atmosphere, it egins to exhale more carbonic acid than it decomposes; and the ame is the case, as just now stated, in regard to leaves that have early reached the term of their lives. It does not admit of uestion, however, that, under ordinary circumstances, nearly the rhole carbon of a slow-growing plant is derived from the carbonic cid of the atmosphere; either directly through the leaves, or in-irectly by absorption through the roots; and that there must be a ast surplus, therefore, of the carbonic acid decomposed, over that rhich is exhaled, during the whole life of the tree,—that surplus eing in fact represented by the total amount of carbon contained ı its tissues.

86. It is probable that the minute amount of Carbonic Acid at resent contained in the atmosphere is as much as could be bene-cially supplied to Plants, under the average amount of light to rhich they are subjected, over the whole globe, and throughout ıe year. Yet it has been found by experiment, that, under the ıfluence of strong sunlight, an atmosphere containing as much as or 8 per cent. of carbonic acid may be not merely tolerated by 'lants, but may be positively beneficial to them, producing a great cceleration in their growth: as soon as the light is withdrawn, owever, this excess acts upon them most injuriously, causing ıem speedily to become unhealthy, and altogether destroying ıeir vitality if they be long subjected to it. Under more cloud-ss skies than ours, the continual supply of a larger quantity of ırbonic acid than our atmosphere contains, is found to be quite ompatible with healthy vegetation; especially in the case of ryptogamic plants, which (as will be presently shown) require a ss amount of light than do those of a higher kind. Thus in the ıke Solfatara in Italy, an unusual supply of carbonic acid is fforded by the constant escape of that gas from fissures in the ed of the lake, with a violence that gives to the water an ap-earance of ebullition; and on its surface there are numerous oating islands, which consist almost entirely of Confervæ and ther simple cellular plants, growing most luxuriantly in this rich abulum. And it has been remarked, that the vegetation around ıe springs in the valley of Göttingen, which abound in carbonic cid, is very rich and luxuriant; appearing several weeks earlier ı the spring, and continuing much later in the autumn, than at

other spots in the same district. Many circumstances lead to the belief, that at former epochs in the Earth's history the atmosphere was much more highly charged with Carbonic Acid than at present; and that to this circumstance, in conjunction with a more intense and constant influence of Light and Heat, we are to attribute that extraordinary luxuriance of the vegetation of those periods, of which we have most abundant evidence, not only in the vast beds of disintegrated vegetable matter—Coal—that are of such value to Man, but also in the remains which have been more perfectly preserved to us, and which indicate that not only the genera forest-mass, but many of the individual forms, attained a degree of development which can scarcely now be paralleled even between the Tropics.

87. Although this fixation of carbon by the decomposition o carbonic acid (with which it is probable that the decomposition o ammonia is intimately associated), is the most universally de pendent of all the processes of the Vegetable economy upon th influence of Light, yet it is not the only one, especially amon the higher Plants, to which that influence supplies an importan condition. Of the whole quantity of moisture imbibed by th roots and contained in the ascending sap, a large proportion is *ex haled* again by the leaves; a small part only being retained (to gether with the substances previously dissolved in the whole) t form part of the fabric. Now upon the rapidity of this exhalatior depends the rapidity of the absorption; for the roots will not con tinue to take-up more than a very limited amount of fluid, when is not discharged again from the opposite extremity (so to speak) the stem. The loss of fluid by the leaves appears to be a simpl process of evaporation, depending in great part upon the tempera ture and dryness of the surrounding air; this evaporation, how ever, does not take-place solely or even chiefly from the extern surface of the leaves, but from the walls of the passages which a channelled-out in their interior. Into this complex labyrinth, th outer air finds its way through orifices in the cuticle, which a termed *stomata;* and through these it comes-forth again, charge with a large amount of vapour communicated to it by the exte sive moist surface with which it comes into contact in the interi of the leaf. Now the stomata are bounded by two or more cells, such a manner that they can be opened or closed by changes in th form of these; and this alteration is regulated by the amount Light to which the leaves are subjected. When the stomata a opened under the influence of light, the external air is free admitted to the extended surface of moist tissue within the lea and a rapid loss of fluid is the result; more especially if the ten perature be high, and the atmosphere in a dry state. On th other hand, if the stomata be closed, the only loss of fluid th can take-place from the internal tissue of the leaves, is throug

the cuticle; the organization of which seems destined to enable it to resist evaporation, so that the exhalation is almost entirely checked.—The influence of Light upon this important function is easily shown by experiment. If a plant which is actively transpiring and absorbing under a strong sunshine, be carried into a dark room, both these operations are almost immediately checked, even though the surrounding temperature be higher than that to which the plant was previously exposed.

88. The effect of the complete and continued withdrawal of Light from a growing plant, is to produce an *etiolation* or blanching of its green surfaces; a loss of weight of the solid parts, owing to the continued disengagement of carbon from its tissues, unbalanced by the fixation of that element from the atmosphere; a dropsical distension of the tissues, in consequence of the continued absorption of water, which is not got-rid-of by exhalation; a want of power to form its peculiar secretions, or even to generate new tissues, after the materials previously stored-up have been exhausted; in fine, a cessation of all the operations most necessary to the preservation of the vitality of the structure, of which cessation its death is the inevitable result. A partial withdrawal of the influence of light, however, is frequently used by the Cultivator, as a means of giving an esculent character to certain plants which would be otherwise altogether uneatable; for in this manner their tissues are rendered more succulent and less 'stringy,' whilst their peculiar secretions are formed in diminished amount, and communicate an agreeable flavour instead of an unwholesome rankness of taste.

89. There is one period in the life of the Flowering-plant, however, in which the influence of Light is rather injurious than beneficial; this is during the first part of the process of Germination of seeds, which is decidedly retarded by its agency. Yet there is here no exception to the general rule; since the decomposition of the carbonic acid of the atmosphere, and the fixation of of carbon in the tissues, do not constitute a part of the operation. On the contrary, the embryo being nourished, like an animal, by organic compounds previously elaborated and stored-up in the seed, the chemical changes which take-place in them involve the opposite action,—the extrication of carbon, which is converted into carbonic acid by uniting with the oxygen of the atmosphere. It is obvious, then, why light should not only be useless, but even prejudicial to this process; since it tends to fix in the tissues the carbon which ought to be thrown-off. As soon, however, as the cotyledons or seed-leaves are unfolded, the influence of light upon them becomes as important as it is on the ordinary leaves at a subsequent time; their surfaces become green, and the fixation of carbon from the atmosphere commences. Up to that period, the young plant diminishes day by day (like a plant that is undergo-

ing etiolation) in the weight of its solid contents, although its bulk increases by the absorption of water. From the time, however that its cotyledons begin to act upon the air, under the influence of Light, the quantity of solid matter begins to augment; and its augmentation subsequently continues, at a rate proportional to the amount of green surface exposed, and to the degree of light to which it is subjected.

90. The influence of Light upon the direction of the growing parts of Plants, upon the opening and closing of flowers, &c., is probably due to its share in the operations already detailed. Thus the green parts of Plants, or those which effect the decomposition of carbonic acid (such as the leaves and stems), have a tendency to grow towards the light; whilst the roots, through whose dark surfaces carbonic acid is thrown out by respiration, have an equal tendency to avoid it. That the first direction of the stems and roots of plants is very much influenced in this manner, appears from the fact, that, by reflecting light upon germinating seeds, in such a manner that it shall only fall upon them from below, the stems are caused to direct themselves downwards, whilst the roots grow upwards.—There can be no doubt, however, that Light has also a more direct influence on the development of particular organs in certain Vegetables. Thus when the *gemmules** of the *Marchantia polymorpha* (one of the *Hepaticæ* or Liverworts) are in process of development, it has been shown by repeated experiments, that stomata are formed on the side exposed to the light, and that roots grow from the lower surface; and that it is a matter of indifference *which* side of the little disk is at first turned upwards, since each has the power of developing either stomata or roots, according to the influence it receives. After the tendency to the formation of these organs has once been given, however, by the sufficiently-prolonged influence of light upon one side, and of darkness and moisture upon the other, any attempt to alter it is found to be vain; for if the surfaces be then inverted, they are soon restored to their original aspects by the twisting growth of the frond or leafy expansion.

91. The same amount of this agent is not requisite or desirable for all plants; and we find in the different *habitats* which are characteristic of different species, even amongst our native plants, that the amount congenial to each varies considerably. Generally speaking, the succulent thick-leaved Plants require the largest amount of light; their stomata are few in number, and its full influence is requisite to induce sufficient activity in their exhaling

* These gemmules are analogous to the *buds* of higher plants; and they consist of little collections of cells, having the form of flat disks, which are at first attached by footstalks arising from the bottom of little basket-shaped conceptacles evolved from the surface of the fronds of the parent-plant, but afterwards fall-off and are developed into new fronds.

process; accordingly we find them growing for the most part in exposed situations, where there is nothing to interfere with the free action of the solar rays. On the other hand, plants with thinner and more delicate leaves, in which the exhaling process is easily excited to an excessive amount, evidently find a congenial home in more sheltered situations; and there are some which can only develope themselves in full luxuriance, in the deep shades of a plantation or a forest. By a further adaptation of the same kind, some species of Plants are enabled to live and acquire their green colour, under an amount of deprivation which would be fatal to most others; thus in the mines of Freyberg, in which the quantity of light admitted must be almost infinitesimally small, Humboldt met with Flowering-plants of various species; and mustard and cress have been raised in the dark abysses of the collieries of this country.

92. Generally speaking, however, the Cryptogamia would seem to be better adapted than Flowering-plants to carry on their vegetating processes under a low or very moderate amount of this agency. Thus Humboldt found a species of Sea-weed near the Canaries, which possessed a bright grass-green hue, although it had grown at a depth of 190 feet in the sea, where, according to computation, it could have received only 1-1500th part of the solar rays that would have fallen upon it at the surface of the ocean. Many Ferns, Mosses, and Lichens seem as if they avoided the light, choosing the northern rather than the southern sides of hedges, buildings, &c., for their residence; so that the former often present a luxuriant growth of Cryptogamic vegetation, whilst the latter are comparatively bare. It must not be supposed, however, that they avoid light altogether, but only what is to them an excessive degree of it. The avoidance of light seems to be much stronger in the Fungi, which grow most luxuriantly in very dark situations; and the reason of this is probably to be found in the fact, that, like the germinating seed (§ 89), they form, rather than decompose, carbonic acid; their food being supplied to them from the decaying substances on which they grow; and the rapid changes in their tissues giving rise to a high amount of Respiration,—a change exactly the converse of that on which, as we have seen, Light exerts such a remarkable power.

93. In regard to the agency of Light upon the functions of Animals, comparatively little is certainly known. It is evident that the influence it exerts on those chemical processes which constitute the first stage of Vegetable nutrition, can have scarcely any place in Animals; because *they* do not perform any such acts of combination, but make use of the products already prepared for them by Plants. Hence we do not find that the *surface* of Animals undergoes that extension, for the purpose of being exposed to the solar rays, which is so characteristic a feature in the Vegetable

fabric, and is so important in its economy. Still there can be no doubt, that the degree of exposure to light has a great influence upon the *colours* of the Animal surface; and here we seem to have a manifestation of Chemical agency, analogous to that which gives colour to the Vegetable surface. Thus it is a matter of familiar experience, that the influence of light upon the skins of many persons causes it to become spotted with brown *freckles;* these freckles being aggregations of brown 'pigment-cells,' which either owed their development to the agency of light, or were enabled by that agency to perform a chemical transformation which they could not have otherwise effected. In like manner, the swarthy hue which many persons acquire in warm climates, is due to a development of dark pigment-cells, diffused through the epidermis (§ 229); and an increase of the same kind of action gives-rise to the blackness of the Negro-skin. There can be no doubt that the prolonged influence of light upon one generation after another, tends to give a permanent character to this variety of hue; which will probably be more easily acquired, in proportion to the previously-existing tendency to that change. Thus it is well known that a colony of Portuguese Jews, which settled at Tranquebar about three centuries ago, and which has kept itself distinct from the surrounding tribes, cannot now be distinguished as to colour from the native Hindoos. But it is probable that a similar colony of fair-skinned Saxons would not, in the same time, have acquired anything like the same depth of colour in their skins. It can scarcely be questioned that the brilliancy of colour which is characteristic of many tribes of animals in tropical climates, especially Birds and Insects, is in great part dependent, like the brightness of the foliage and fruit of the same countries, upon the brightness of the light to which their surfaces are exposed. When birds of warm climates, distinguished by the splendour of their plumage, are reared under an artificial temperature in our own country, it is uniformly observed, that they are much longer in acquiring the hues characteristic of the adult; and that these are never so bright as when they have been produced under the influence of the tropical sun. And it has been also remarked that if certain Insects (the Cockroach for example), which naturally inhabit dark places, be reared in an *entire* seclusion from light, they grow-up almost as colourless as Plants that are made to vegetate under similar circumstances.

94. There is reason to believe that Light exercises an important influence on certain processes of *development* in Animals, as well as in Plants. Thus, the appearance of Animalcules in infusions of decaying organic matter is much retarded, if the vessel be altogether secluded from it. The rapidity with which the small Entomostracous Crustacea (water-fleas, &c.) of our pools, undergo their transformations, has been found to be much influenced by the

nount of light to which they are exposed. And it has been scertained that, if equal numbers of Silk-worm's eggs be pre-rved in a dark room, and be exposed to common daylight, a much rger proportion of larvæ are hatched from the latter than from ie former. Numerous facts, collected from different sources, lead the belief that the healthy development of the Human body, id the rapidity of its recovery from disease, are greatly influenced y the amount of Light to which it has been exposed. It has een observed, on the one hand, that a remarkable freedom from eformity exists amongst nations who wear very little clothing; hilst, on the other, it appears certain that an unusual tendency malformation is to be found among persons brought-up in ellars or mines, or in dark and narrow streets. Part of this dif-erence is doubtless owing to the relative purity of the atmosphere 1 the former case, and the want of ventilation in the latter; but ther instances may be cited, in which a marked variation has resented itself under circumstances otherwise the same. Thus, has been stated by Sir A. Wylie (who was long at the head of ie medical staff in the Russian army), that the cases of disease n the dark side of an extensive barrack at St. Petersburg, bore niformly for many years the proportion of three to one, those on the side exposed to strong light. And in one of the ondon Hospitals, with a long range of frontage looking nearly ue north and south, it has been observed, that residence in the outh wards is much more conducive to the welfare of the patients, han in those on the north side of the building.

95. Some curious facts have recently become known, which eem to indicate that the development of the Visual organs is so far elated to the presence of Light, that complete seclusion from that gent during a long succession of generations will prevent their ppearance. Thus in the deep caverns of Styria and Carniola, we ot only find the *Proteus* (an animal which closely corresponds in ts fully-developed form with the transition stage between the adpole and the Frog), that inhabits their dark lakes, to be desti-ute of eyes; but these caves also contain a considerable number f species of Insects, all of them characterized by the same eficiency. So it has been found that the vast cave of Kentucky s tenanted not only by a blind Fish, the *Ambylopsis*, but also by umerous blind Insects. Now it has been very justly remarked y Mr. Darwin, that if these two sets of blind animals had been eparately created for the express purpose of peopling the European nd American caverns, a very close similarity in their organization nd affinities might have been expected. This, however, is not he case; the mutual resemblances of the two series being only uch as would be expected from the general analogy subsisting etween the Fauna of Europe and that of North America; whilst he special affinities of the animals of each series are in almost

every instance to the inhabitants of the neighbouring regions. So that it cannot be deemed improbable that the blind inhabitants of the caves are the descendants of originals still represented by perfect forms outside. And this seems the more likely from the well-known fact, that if in the Human eye the admission of light to the retinal surface be *entirely* prevented by complete opacity of the anterior part of the globe, the nervous tissue of the retina and optic nerve becomes atrophied, and the whole eye diminishes in size.

96. These facts being kept in view, it is easy to perceive that there must be differences among the various species of Animals, as among those of Plants, in regard to the degree of light which is congenial to them. Among the lowest tribes, in which no special organs of vision exist, there is evidently a susceptibility to the influence of light, which appears scarcely to deserve the name of 'sensibility,' but which seems rather analogous to that which is manifested by Plants; thus among those Polypes which are not fixed to particular spots, and amongst Animalcules, there are some species which seek the light, and others which shun it. And it appears from various observations upon the depths at which marine animals are found, especially from the extensive series of facts collected by Prof. E. Forbes,* that there are a series of *zones*, so to speak, to be met-with in descending from the surface towards the bottom of the ocean, each of which is characterized by certain species of animals peculiar to itself, whilst other species have a range through two or more of the zones;—the extent of the range of depth, in each species, bearing a close correspondence with the extent of its geographical distribution. Now there can be no doubt, that the restriction of particular species to particular zones is due in great part to the degree of *pressure* of the surrounding medium; but there can be as little doubt that the variation in the degree of Light also exerts a most important influence, the solar rays in their passage through sea-water being subject to a loss of one-half for every seventeen feet.

2. *Of Heat, as a Condition of Vital Activity.*

97. The most perfectly-organized body, supplied with all the other conditions requisite for its activity, must remain completely inert, if it do not receive a sufficient amount of Heat. The influence which this agent exerts upon Living beings is far more remarkable than its effects upon Inorganic matter; although the latter are usually more obvious. We are all familiar with its power of producing expansion,—with the liquefaction which is the consequence of its application to solids, — with the evaporation which it occasions in liquids, — and with the enormous repulsive

* Report on the Invertebrata of the Ægean Sea, in Transactions of British Association, 1843.

rce which it generates among the particles of vapours; but it is ot until we look deeper than the surface, that we perceive how nmediate is the dependence of every action of Life upon this owerful agent. The temporary or permanent loss of vitality, in rts of the body subjected to extreme cold, is a 'glaring instance' the effect of its withdrawal. This change, however, is not im-ediate. Its first step is a mere depression of the vitality of the rt, involving a partial stagnation of the capillary circulation, minution of sensibility, and want of muscular power. But the ntinued action of cold on the surface, not compensated by a fficient generation of heat within, causes the circulation of the rt to be completely suspended; its small vessels contract, so that ey become almost emptied of blood; its sensibility and power of ovement are destroyed; — in a word, its vital activity is com-etely suspended. In such a state, a timely but cautious applica-on of warmth may produce the gradual renewal of the circulation, d the restoration of the other powers which are dependent upon at function; but any abrupt change would complete the mischief hich the cold has begun; and would altogether destroy, by the olence of the reaction, the vitality which was only suspended, using the actual *death* of the part. Hence, when the extremi-es are 'frost-bitten,' nothing can be more injurious than to bring em near a fire; whilst no treatment has been found so safe and fectual, as the rubbing them with snow.

98. The influence of Heat upon Vital activity is attested on a rger scale, by the striking contrast between the dreary barren-ss of Polar regions, and the luxuriant richness of Tropical coun-ies, where almost every spot to which moisture is supplied teems ith Animal and Vegetable life. And the alternation of Winter d Summer in temperate climates, may be almost said to bring nder our own view the opposite conditions of those two extreme ses. The effect of the withdrawal of Heat is most obvious in e Vegetable kingdom; since all its operations are dependent upon certain supply of that agent; and in no case are Plants possessed the power of generating that supply within themselves, except-g in certain organs which do not impart it to the rest of the ructure. When the temperature of the air falls to the freezing int, therefore, we find all the operations of the Vegetable onomy undergoing a complete suspension; yet a very trifling se will produce a renewal of them. It is not only in Evergreens at the vital processes continue to be performed to a certain ex-nt during the winter; for there is abundant evidence that, even the trunk and branches of trees unclothed with leaves, a circu-tion of sap takes place, whenever there is even a slight return f warmth. In this manner, the leaf-buds are gradually prepared uring the milder days of winter, so as to be ready to start-forth to full development with the returning steady warmth of spring.

99. The influence of Heat upon Vegetation is easily made apparent by experiment; in fact, experimental illustrations of it, on a large scale, are daily in progress. For the Gardener, by artificial warmth, is not only enabled to rear with success the plants of tropical climates, whose constitution would not bear the chilling influence of our winter;—but he can also, in some degree, invert the order of the seasons, and produce both blossom and fruit from the plants of our own country, when all around seems dead. This process of *forcing*, however, is unfavourable to the health and prolonged existence of the plants subjected to it; since the period of repose which is natural to them is interrupted, and they are caused, as it were, to live too fast. The same result occurs when a plant or tree of temperate climates is transported to the tropics. Within a very short period after one crop of leaves has fallen-off, a new one makes its appearance. This goes through all its changes of development and decay more rapidly than it would do in its native clime; and in its turn falls off, to be speedily succeeded by another. Hence the fruit-trees of this country, transported to the East or West Indies, bear abundant crops of leaves, — three, perhaps, in one year, or five in two years, — but little or no fruit; and the period of their existence is much shortened.

100. As Plants are almost wholly dependent upon the surrounding medium for the supply of Heat necessary for their growth, many regions must have been devoid of Vegetable life altogether, if there were not a remarkable adaptation, in the wants of different species, to the various degrees of temperature of the habitations prepared for them. Thus the Lichen which serves as the winter food of the Rein-deer, spreads itself over the ground whilst thickly covered with snow; and the beautiful little *Protococcus nivalis*, or 'red snow,' reddens extensive tracts in the arctic regions, where the perpetual frost of the surface scarcely yields to the influence of the solar rays at Midsummer. On the other hand, we see the Cacti and Euphorbiæ attaching themselves to the surface of the most arid rocks of tropical regions, luxuriating, as it would seem, in the full glare of the vertical sun, and laying-up a store of moisture from the periodical rains, of which even a long-continued drought is not sufficient to deprive them. The Orchideous tribe, on the other hand, whose greatest development occurs in the same zone, find their congenial habitation in the depths of the tangled forests, where, with scarcely an inferior amount of heat, they have the advantage of moister atmosphere, caused by the exhalations of the trees on which they cling. The majestic Tree-Fern, again, reaches its full development in insular situations; where, with a moist atmosphere, it can secure a greater equability of temperature than is to be met-with in the interior of the vast tropical continents. None of these races can develope themselves elsewhere, to their full extent at least, unless their natural con-

tions of growth are imitated as far as possible; and in proporon as this imitation can be made complete, in that proportion ay the plant of the tropics be successfully reared in temperate gions.

101. There are some examples of the adaptation of particular rms of Vegetable life to extremely high temperatures, which are teresting as showing the extent to which this adaptation may be rried. In hot springs near a river of Louisiana, of the temperaure of from 122° to 145°, there have been seen to grow, not erely Confervæ and herbaceous plants, but shrubs and trees; id a hot-spring in the Manilla islands, which raises the therometer to 187°, has plants flourishing in it and on its borders. species of Chara has been found growing and reproducing itself one of the hot-springs of Iceland which boiled an egg in four inutes; various Confervæ, &c., have been observed in the boiling rings of Arabia and the Cape of Good Hope; and at the island New Amsterdam there is a mud-spring, which, though hotter an boiling-water, gives-birth to a species of Liverwort.

102. It is, for the most part, among the Cryptogamic tribes, — e Ferns, Mosses, Liverworts, Fungi, and Lichens, — that the eatest power of growing under a low temperature exists; and we cordingly find that the proportion of these to the Phanerogamia Flowering-plants, increases as we proceed from the Equator wards the Poles. It has been estimated by Humboldt, that, in ropical regions, the number of species of Cryptogamia is only oout *one-tenth* that of the Flowering-plants; in the part of the emperate zone which lies between Lat. 45° and 52°, the proporon rises to *one-half;* and the relative amount gradually increases we proceed towards the Poles, until, between Lat. 67° and 70°, e number of species of Cryptogamia *equals* that of the Phaneroimia. Among the Flowering-plants, moreover, the greatest idurance of cold is to be found in those which approach most early to the Cryptogamia in the low degree of their development; us the Glumaceous group of Endogens, including the Grasses, ushes, and Sedges, which forms about *one-eleventh* of the whole nount of Phanerogamic vegetation in the Tropics, constitutes *ie-fourth* of it in the Temperate regions, and *one-third* in the olar; and the ratio of the Gymnospermic group of Exogens, hich chiefly consists of the Pine and Fir tribe, increases in like anner. Still, the influence of a high temperature is evident even oon the Cryptogamia and their allies; for it is only under the fluence of the light and warmth of tropical climes, that the erns, — the highest among the former, — can develope a woody em, and assume the character of trees; and it is only there that e tall Sugar-Canes and the gigantic Bamboos, which are but rasses on a large scale, can flourish.

103. It appears, then, that to every species of Vegetable there

is a temperature which is most congenial, as producing the most favourable influence on its general vital actions. There is a considerable difference between the power of *growing,* and of *flourishing,* at a given temperature. We may lower the heat of a plant to such a degree as to allow it to continue to live; yet its condition will be unhealthy. It absorbs food from the earth and air, but cannot assimilate and convert it. Its tissue grows, but becomes distended with water, instead of being rendered firm by solid deposits. The usual secretions are not formed; flavour, sweetness, and nutritive matter, are each diminished; and the power of flowering and producing fruit is lost. We see a difference in the amount of heat required for the vegetating processes, even in the various species indigenous to our own climate; thus the common Chickweed and Groundsel evidently grow readily at a temperature but little above the freezing point, whilst the Nettles, Mallows, and other weeds around them, remain torpid. But the difference is much more strongly marked in the vegetation of different climates; showing an evident adaptation of the tribes indigenous to each, to that range of temperature which they will there experience. Instead of being scantily supplied with such of the tropical plants as could support a stunted and precarious life in ungenial climates, the temperate regions are stocked with a multitude of vegetables which appear to be constructed expressly for them; inasmuch as these species can no more flourish at the Equator, than the equatorial species can thrive in the temperate regions. And such new supplies, adapted to new conditions, recur perpetually as we advance towards the apparently frozen and untenantable regions in the neighbourhood of the Pole. Every zone has its peculiar vegetables; and while we miss some, we find others making their appearance, as if to replace those which are absent.

104. Thus in the countries lying near the Equator, the vegetation consists in great part of dense forests of leafy Evergreen trees, Palms, Bamboos, and Tree-Ferns, bound-together by clustering Orchideæ, and strong creepers of various kinds. There are no verdant meadows, such as form the chief beauty of our temperate regions; and the lower orders of Vegetation are extremely rare. It is only in this torrid zone, that Dates, Coffee, Cocoa, Bread-fruit, Bananas, Cinnamon, Cloves, Nutmegs, Pepper, Myrrh, Indigo, Ebony, Logwood, Teak, Sandal-wood, and many others of the vegetable products most highly valued for their flavour, their odour, their colour, or their density, come to full perfection. As we recede from the Equator, we find the leafy Evergreens giving place to trees with deciduous leaves; rich meadows appear, abounding with tender herbs; the Orchideæ no longer find in the atmosphere, and on the surface of the trees over which they cluster, a sufficiency of moisture for their support, and the parasitic species are replaced by others which grow from fleshy roots, implanted in

he soil; but aged trunks are now clothed with Mosses; decayed egetables are covered with parasitical Fungi; and the waters bound with Confervæ. In the warmer parts of the temperate egions, the Apricot, Citron, Orange, Lemon, Peach, Fig, Vine, live, and Pomegranate, the Myrtle, Cedar, Cypress, and Dwarf Palm, find their congenial abode. These give-place, as we pass orthwards, to the Apple, the Plum, and the Cherry, the Chestnut, he Oak, the Elm, and the Beech. Going further still, we find hat the fruit-trees are unable to flourish, but the timber-trees aintain their ground. Where these last fail, we meet with ex-ensive forests of the various species of Firs; the Dwarf Birches nd Willows replace the larger species of the same kind; and even ear or within the arctic circle, we find wild flowers of great eauty,—the Mezereon, the yellow and white Water-Lily, and the lobe-flower. Where none of these can flourish, where trees holly disappear, and scarcely any flowering-plants are to be met ith, an humbler Cryptogamic vegetation still raises its head, in roof that no part of the Globe is altogether unfit for the residence f living beings, and that the empire of Flora has no limit.

105. But distance from the Equator is by no means the only lement in the determination of the mean temperature of a par-icular spot, its height above the level of the sea being equally mportant; for this produces a variation in the amount of heat erived from the Sun, at least as great as that occasioned by differ-nce of latitude. Thus it is not alone on the summits of Hecla, Iount Blanc, and other mountains of arctic or temperate regions, hat we find a coating of perpetual snow; we find a similar cover-ng on the lofty summits of the Himalayan chain which extends within a few degrees of the tropic of Cancer, and even on the igher peaks of that part of the ridge of the Andes which lies mmediately beneath the Equator. The height of the *snow-line* eneath the Equator is between 15,000 and 16,000 feet above the evel of the sea; on the south side of the Himalayan ridge, it is bout 15,500 feet, but on the north side it rises to 18,500 feet; nd in the Swiss Alps it is about 8,000 feet.

106. If, then, Temperature exert such an influence on Vegetable fe as has been stated, we ought to find on the sides of lofty moun-ains in tropical regions, the same progressive alterations in the haracters of the Plants that cover them, as we encounter in jour-eying from the equatorial towards the polar regions. This is ctually the case. The proportion of Cryptogamia to Flowering lants, for example, is no more than *one-fifteenth* on the *plains* of e Equatorial region; whilst it is as much as *one-fifth* on the *ountains*. In ascending the Peak of Teneriffe, Humboldt ob-erved as many as five distinct zones, which were respectively arked by the products which characterize different climates. hus at the base, the vegetation is altogether tropical; the Date-

Palm, Plantain, Sugar-Cane, Banyan, the succulent Euphorbia, the Dracæna, and other trees and plants of the torrid zone there flourish. A little higher grow the Olive, the Vine, and other fruit-trees of Southern Europe; there Wheat flourishes; and there the ground is covered with grassy herbage. Above this is the woody region, in which are found the Oak, Laurel, Arbutus, and other beautiful hardy evergreens. Next above is the region of Pines; characterized by a vast forest of trees resembling the Scotch Fir, intermixed with Juniper. This gives-place to a tract remarkable for the abundance of Broom; and at last the scenery is terminated by Scrofularia, Viola, a few grasses, and Cryptogamic plants, which extend to the borders of the perpetual snow that caps the summit of the mountain.

107. The effects of Temperature on Vegetation are not only seen in its influence upon the Geographical distribution of Plants, that is, in the limitation of particular species to particular climates; for they are shown, perhaps even more remarkably, in the variation in the size of individuals of the same species, when that species possesses the power of adapting itself to widely-different conditions, which is the case with some. Thus the *Cerasus Virginiana*, which rears itself in the southern states of North America as a noble tree attaining one hundred feet in height, when growing in the sandy plains of the Saskatchawan does not exceed twenty feet, whilst at its northern limit, the Great Slave Lake, in Lat. 62°, it is reduced to a shrub of five feet. Another curious effect of heat is shown in its influence on the sexes of certain Monœcious flowers: thus Mr. Knight mentions that Cucumber and Melon plants will produce none but male or staminiferous flowers, if their vegetation be accelerated by heat; and all female or pistilline, if its progress be retarded by cold.

108. The injurious influence of excessive Heat can be, to a certain extent, resisted by Plants, through the cooling process kept-up by the continual evaporation of moisture from their surface. But the power of maintaining this cooling process entirely depends upon the supply of fluid with which the plant is furnished. If the supply be adequate to the demand, the effect of heat will be to stimulate all the vital operations of the plant, and to cause them to be performed with increased energy; though, as we have already seen, this energy may be such as to occasion a premature exhaustion in its powers, by the excessive luxuriance which it occasions. But if the supply of water be deficient, the plant is burnt-up by the continuance of heat in a dry atmosphere; and it either withers and dies, or its tissues become dense and contracted without losing their vitality. Thus, shrubs growing among the sandy deserts of the East have as stunted an appearance as those attempting to vegetate in the Arctic regions; their leaves being converted into prickles, and their leaf-buds prolonged

ito thorns instead of branches.—The influence of excessive heat ı destroying life can sometimes be traced through the direct ıysical changes which it occasions in the vegetable tissues. Thus has been ascertained that grains of corn will vegetate after kposure to water or vapour possessing a considerable degree of ɘat, provided such heat do not amount to 144° in the case of ater, and 167° in that of vapour; for at these temperatures, the ructure of the seed undergoes a disorganizing change, by the ıpture of the vesicles of starch which form a large part of it, so ıat the loss of its power of germinating is readily accounted-for. he highest temperature which the soil usually possesses in tro- cal climates, is about 126°, though Humboldt once observed the ıermometer rise to 140°. Seeds imbedded in such a soil, there- re, may not lose their vitality, although they will not germinate such temperatures. The temperature most favourable to ger- ination probably varies in different species, and is one of the nditions that produces their adaptation to different climates. hus it appears, that Corn will not germinate in water at a higher mperature than 95°, whilst Maize will germinate in water at 13°; and, as is well known, Maize will flourish in countries in hich Corn cannot be grown.

109. We must not confound the power which plants possess of *getating*, or exhibiting *vital activity*, under widely-different de- ees of temperature, with the power of retaining their *vitality* in dormant condition, which many of them possess in a very re- arkable degree. When the external temperature is much below ıe freezing-point, it is impossible that any vegetating processes n go-on; since the Plant does not possess the power of gene- ting heat within itself. Now such a complete cessation of tivity is quite compatible, in many instances, with the preser- ıtion of the organized structure in a condition perfectly un- ıanged, and, in consequence, with the continuance of its peculiar operties; so that these properties may be again called into eration when the temperature shall have risen. But in other ses, the plant may be *killed* by the intensity of the cold; that the return of warmth will not excite it to activity. We have casion to notice, in every severe winter, the difference in this spect amongst the plants which are cultivated in our own imate; some of them being killed by a hard frost, the effects of hich are resisted by others, even though their situation be more posed. In general it will be found, that the cold acts most werfully (as might be expected) upon plants which are not digenous to our country, but which have been introduced and ıturalized from some warmer regions. But it is worthy of note, ıongst other peculiarities in the relation of Heat and Vegetation, at many plants are readily killed by a low temperature, which t flourish well under a very moderate amount of warmth; so

that they will grow in situations where the mean temperature of the year is low and the summers cool, provided the winters are not severe; whilst they cannot be preserved without special protection, in situations where the winters are colder, even though the summers should be much hotter, and the mean temperature of the whole year should be considerably higher. Thus there are shrubs flourishing in the Botanic Garden of Edinburgh which cannot be safely left in the open air in the neighbourhood of London, and which would be most certainly killed by the winter-cold of central France.

110. It scarcely admits of doubt, that the destructive influence of a very low temperature upon the Vitality of Plants is immediately exerted through its chemical and physical effects upon their fabric. Thus it will produce congelation of their fluids; and the expansion which takes-place in freezing will injure the walls of the containing cells,—distending, lacerating, or even bursting them. The same cause will probably occasion the expulsion of air from some parts which ought to contain it; and the introduction of it into other parts which ought to be filled with fluid. And a separation must take place in the act of freezing, between the constituent parts of the vegetable juices; which will render them unfit for discharging their functions, when returning warmth would otherwise call them into activity. Hence we are enabled in some degree to account for the differences in the power of resisting cold, which the various species of Plants, and even the various parts of the same individual, are found to possess. For, other things being equal, the power of each plant, and of each part of a plant, to resist a low temperature, will be in the inverse ratio of the quantity of water contained in the tissue; thus, a succulent herbaceous plant suffers more than one with a hard woody stem and dense secretions; and young shoots are destroyed by a degree of cold which does not affect old shoots and branches of the same shrub or tree. Again, the viscidity of the fluids of some plants is an obstacle to their congelation, and therefore enables them to resist cold; thus it is that the resinous Pines are, of all trees, those which can endure the lowest temperature. The dimensions of the cells, too, of which the tissue is composed, appear to have an influence; the liability to freeze being diminished by a very minute subdivision of the fluids. And when the roots are implanted deep in the soil, where the temperature does not fall by many degrees so low as that of the surface, the fluidity of the sap may be maintained, in spite of the extremely cold state of the atmosphere. It has been shown, moreover, by Prof. Tyndall, that the heat-conducting power of wood is far less in the direction from the surface to the centre of a stem, than in the direction of its length; so that whilst the coldness of the atmosphere thus exerts a *minimum* of influence upon the temperature of the interior of the trunk, the comparative warmth of the deeper soil has its *maximum* of effect.

111. It is in Cryptogamic plants that the greatest power of sustaining Cold exists; as might be inferred from what has been already stated in regard to their geographical distribution. The little Fungus (*Torula Cerevisiæ*) which is one of the principal constituents of Yeast, does not lose its vitality by exposure to a temperature of 76° *below zero;* though it requires a somewhat elevated temperature for its active growth.—It would appear that *Seeds* are enabled to sustain a degree of cold without the loss of their vitality, which would be fatal to growing plants of the same species; thus grains of corn of various kinds will germinate after being exposed for a quarter of an hour to a temperature equal to that of frozen mercury. It is not difficult to account for this, when the closeness of their texture, and the small quantity of fluid which it includes, are kept in view. The act of Germination, however, will only take place under a rather elevated temperature; and we find, in the Chemical changes which it involves, a provision for maintaining this, when the process has once commenced.

112. The influence of Heat upon the vital activity of Animals, is quite as strongly marked as we have seen it to be in the case of Plants; but the mode in which it is exerted is in many instances very different. In those animals which are endowed with great and sustained energy of muscular movement, and in which, for the maintenance of that energy, the nutritive functions are kept in constant activity, we find that a provision exists for the development of heat from within, so as to keep the temperature of the body at a certain uniform standard, whatever may be the climate in which they live. Their energy and activity are, in fact, so dependent upon the steady maintenance of a high temperature in their bodies, that, if this should sustain any considerable depression, a diminution or even a complete cessation of vital activity takes-place, and even a total loss of vitality may result. In these *warm-blooded* animals, as they are termed, we do not so evidently trace the effects of Heat, because they are constantly being exerted, and because *external* changes have but little influence upon them, unless such changes be of an extreme kind. But if those *internal* operations on which the maintenance of the temperature is dependent, are from any cause retarded or suspended, the effect is immediately visible. In the class of Birds, whose muscular energy and general functional activity are greater and more constant than those of any other animals, the temperature is pretty steadily maintained at from 108° to 112°; and we shall presently see that a depression of the heat of the body to about 80° is fatal. Among Mammalia, the temperature is usually maintained at from 98° to 102°; and it seems that in them, too, a depression of about thirty degrees is ordinarily fatal.

113. In the different tribes of Birds and Mammals, we find a very diversified power of generating heat; and on this depends

their adaptation to various climates. Where the usual temperature of the atmosphere is but little below the normal standard of the body, a small amount of internal calorifying power is required; and accordingly, we find that animals which naturally inhabit the torrid zone, cannot be kept alive elsewhere, except, like the Plants of the same regions, by external heat. On the other hand, the animals of the colder-temperate and frigid climes are endowed with a much greater internal calorifying power; and their covering is adapted to keep-in the heat which they generate. Such animals (the Polar Bear for example) cannot be kept in health, in the summer of our own country, unless means be taken for their refrigeration. The constitution of Man seems to acquire, by habituation to a particular set of conditions through successive generations, an adaptation to differences of climate, of which that of few other animals is susceptible; and thus we find different races of human beings inhabiting countries which are subject to the extremes of heat and cold. The Hindoo or the Negro, suddenly transported to Labrador or Siberia during the depth of winter, would probably sink in the course of a few days, from want of power to generate within his body an amount of heat sufficient to enable it to resist the depressing influence of the external cold; whilst on the other hand, the Esquimaux, suddenly conveyed to the hottest parts of India or Africa, would speedily become the subject of disease, which would probably terminate his life in a short time. It is in the inhabitant of temperate climates, who is naturally exposed during the seasonal changes of his year to a wide range of external temperature, that we find the greatest power of sustaining the extremes of either cold or heat; and yet, even in such, the continued exposure to either extreme during a long series of years, will so much influence the heat producing power, as to prevent the constitution from adapting itself readily to a change of conditions.

114. We see, then, that the variations observable between different races in this respect, are only exaggerations (so to speak) of the alternations which an individual may undergo in the course of a few years; and it is easy to understand how such an adaptation may take place to an increased extent in successive generations;—this being the regular law, not merely in regard to Man, but in regard to other animals placed under new conditions, to which they have a certain, but limited, power of adapting themselves. Thus we find that an European, who has lived for several years in the East or West Indies, suffers considerably from the cold, when he first returns to winter in his native country; his constitution having, for a time, lost some of its power of generating heat. After a few years' residenee, however, this power is commonly recovered to its original extent, unless the age of the individual be too far advanced; but his children, if they have been

not only born, but brought-up, in the hotter climate, experience much greater difficulty in adapting themselves to the colder one.

115. The conditions on which the power of maintaining the heat of the body, in despite of external cold, is dependent, will become the subject of inquiry hereafter (CHAP. XI). It is sufficient here to state, that this power is the result of numerous Chemical changes going-on within the body; and especially of a process analogous to combustion, in which carbon and hydrogen taken-in as food are made to unite with oxygen derived from the atmosphere. It is dependent, therefore, as to its amount, upon the due supply of the combustible material on the one hand, and of atmospheric air on the other. If the former be not furnished either by the food, or by the fatty matter of the body (which acts as a kind of reserve store laid-up against the time of need), the heat cannot be maintained; and it is in part for want of power to digest and assimilate a sufficient amount of this kind of aliment, that animals of warm climates cannot maintain their temperature in colder regions. On the other hand, if the supply of oxygen be deficient, as it is when the respiration is impeded by diseased conditions of various kinds, there is a similar depression of temperature.

116. Now if, from either of these causes, the temperature of the body of a Bird or Mammal (except in the case of the *hybernating* species of the latter, to be presently noticed), be lowered to about 30° below its usual standard, not only is there a cessation of vital *activity*, but a total loss of vital *properties;* in other words, the *death* of the animal is a necessary result. This occurrence is preceded by a gradually-increasing torpidity; which shows the depressing influence of the cooling process upon the functions in general. The temperature of the superficial parts of the body is, of course, affected earliest; the circulation is at first retarded, causing lividity of the skin; but, as the temperature becomes lower, the blood is almost entirely expelled from the surface by the contraction of the vessels, and paleness succeeds. At the same time there is a gradually-increasing torpor of the nervous and muscular systems, which first manifests itself in an indisposition to exertion of any kind, and then in an almost irresistible tendency to sleep. The respiratory movements become slower, from the want of the stimulus that should be given by the warm current of blood to the Medulla Oblongata, which is the centre of those movements; and the loss of heat goes-on, therefore, with increased rapidity, until the temperature of the whole body is so depressed that its vitality is altogether destroyed.

117. But when there is a deficiency of the proper *animal* heat, the vital activity of the system may be maintained by caloric supplied by external sources. This fact is of high scientific value, as giving the most complete demonstration of the *immediate* dependence of the vital functions of warm-blooded animals upon a

sustained temperature; and its practical importance can scarcely be over-rated. It rests chiefly upon the experiments of Chossat, who had in view to determine the circumstances attending death by Inanition or starvation. He found that when Pigeons were entirely deprived of food and water, their average temperature undergoes a tolerably-regular diminution from day to day; so that after several days (the exact number varying with their previous condition), it is about $4\frac{1}{2}°$ lower than at first. Up to this time, it seems that the store of fat laid-up in the body supplies the requisite material for the combustive process; so that no very injurious depression of temperature occurs. But, as soon as this is exhausted, the temperature falls rapidly from hour to hour; and by the time that the total depression reaches $29\frac{1}{2}°$ or $30°$, death supervenes. Yet it was found by M. Chossat, that when animals thus reduced by starvation, whose death seemed impending (death actually taking place in many instances whilst the preliminary processes of weighing, the application of the thermometer, &c., were being performed), were subjected to artificial heat, they were almost uniformly restored from a state of insensibility and want of muscular power, to a condition of comparative activity. Their temperature rose, their muscular power returned, they took food when it was presented to them, and their secretions were renewed; and if this artificial assistance was sufficiently prolonged, and they were supplied with food, they recovered. If the heat was withdrawn, however, before the time when digested food was ready in sufficient amount to supply the combustive process, they still sank for want of it.

118. Various important practical hints may be derived from the consideration of these facts. There can be no doubt that in many diseases of exhaustion, the want of power to sustain the requisite temperature is the *immediate* cause of death; the whole combustible material of the body having been exhausted, and the digestive apparatus not being able to supply what is required. Now where this is the case, life may be prolonged and recovery favoured by the judicious sustentation of the temperature of the body. This may be effected either by internal or by external means. Of the internal, the most efficient is undoubtedly the moderate administration of Alcoholic fluids; which, for reasons hereafter to be given (§ 495), will be absorbed into the circulating system, when no other alimentary substance can be taken-in; and which, moreover, exert a favourable influence, by their specific stimulating effect, upon the nervous system. But a most important adjunct in all such cases,—and in many instances a substitute for alcohol when the latter would be inadmissible,—will be found in the application of *external* heat; and especially in the subjection of the entire surface to its influence, by means of the hot-air bath. This is a valuable portion of the treatment, in the recovering of

ersons who have been reduced to insensibility by suffocation of ny kind; and especially in cases of drowning, since the heat f the body is rapidly withdrawn by the conducting power of the ater. Indeed it may be stated as a general rule, that, where the emperature of the body is lowered from any cause, *external heat* ay be advantageously applied; and there is evidence that the eparative processes by which extensive wounds are healed, some-mes go-on more favourably under the contact of warm dry air an with any other application.

119. On the other hand, where the object is to keep-down a ndency to a too-violent action, the local application of moderate *ld* is found to be of the greatest value; all surgeons of eminence eing now agreed upon the efficacy of *water-dressing* in restraining e inflammatory process, especially in cases of wounds of the ints, in which this action is most to be apprehended. The *general* pplication of cold to the surface, by means of continued exposure) cool air, or by a short immersion in cold water, is frequently n the highest degree beneficial, by imparting *tone* to the system, *e.*, by producing a firmer condition in the solids which were reviously relaxed, and more especially by calling into action the *nicity* of the walls of the blood-vessels, which imparts to them n increased resistance, and thus favours the regular and vigorous rculation of blood, upon principles which will be hereafter stated § 609). But so far from producing any permanent depression in e temperature of the body, this measure has a tendency to evate it, by the increased vigour it produces in the circulation; ence the glow which is experienced after the use of the cold ath. If this effect be *not* produced, and a chilling of the body, nstead of an invigorating warmth, be the result of the use of cold, is evident that this cannot be beneficial. The injurious results f the too-prolonged application of even a moderate degree of cold, re seen in the depression of temperature, without a corresponding eaction, which is the consequence of an immersion in water of 0° or 55° prolonged for several hours; and still more in that hilling of the whole surface, frequently productive of the most erious consequences, which arises from the evaporation of fluid om garments that have been moistened, either by perspiration om within, or by the fall of rain or dew upon their exterior. here is no doubt that the obstruction to the continuance of the erspiration, produced by the chilling influence of the external vaporation, is one cause of the injurious results that so commonly ollow such an occurrence; for experience shows, that, if the vaporation be prevented by an impenetrable covering, the con-act of a garment thoroughly saturated with moisture is not pro-uctive of the same injurious consequences; but it is probable hat the 'chill' acts also on distant parts, through the medium of he Nervous system.

120. The practical importance of the due comprehension of the principles upon which Heat and Cold should be employed in the treatment of disease and the preservation of health, has required this digression. We now proceed to consider the influence of temperature upon a certain group of warm-blooded animals, which offers a remarkable peculiarity in this respect,—their power of generating heat being for a time greatly diminished or almost completely suspended; the temperature of their bodies following that of the air around, so that it may be brought-down nearly to the freezing-point; their general vital actions being carried-on with such feebleness as to be scarcely perceptible; and yet the vital properties of the tissues being retained, so that, when the temperature of the body is again raised, the usual activity returns. This state, which is called *hybernation*, appears to be as natural to certain animals as sleep is to all; and it corresponds with sleep in its tendency to periodical return.

121. No account can be given of the causes to which Hybernation is due; but the condition of the animals presenting it offers several points of much interest. There are some, as the *Lagomys*, in which it appears to differ but little from deep ordinary sleep; they retire into situations which favour the retention of their warmth; and they occasionally wake-up, and apply themselves to some of the store of food which they have provided in the autumn. In other cases, a great accumulation of fat takes-place within the body in autumn, favoured by the oily nature of the seeds, nuts, &c., on which the animals then feed; and this serves the purpose of maintaining the temperature for a sufficient length of time, not indeed at the usual standard, but at one not far below it. The state of torpor in these animals is more profound than that of deep sleep, but it is not such as to prevent them from being easily aroused; and their respiratory movements, though diminished in frequency, are still peformed without interruption. But in the *Marmot*, and in animals which, like it, hybernate completely, the temperature of the body (owing to the want of internal power to generate heat), and the general vital activity, are proportionably depressed; the respiratory movements fall from 500 to 14 per hour, and are performed without any considerable enlargement of the chest; the pulse sinks from 150 to 15 beats per minute; the state of torpidity is so profound, that the animal is with difficulty aroused from it; and the heat of the body is almost entirely dependent upon the temperature of the surrounding air, not being usually more than a degree or two above it. When the thermometer in the air is somewhat below the freezing-point, that placed within the body falls to about 35°; and at this point it may remain for some time without any apparent injury to the animal, which revives when subjected to a higher temperature. When, however, the body is exposed to a more intense degree of cold, the

nimal functions undergo a temporary renewal; for the cold eems to act like any other stimulus in arousing them. The espiratory movements and the circulation increase in activity, so s to generate an increased amount of heat; but this amount is nsufficient to keep-up the temperature of the body, which is at ast depressed to a degree inconsistent with the maintenance of ife; and not only the suspension of activity, but the total loss of ital properties, is the result.

122. Now the condition of a hybernating Mammal closely reembles that of a cold-blooded animal, in regard to the dependence f its bodily temperature upon external conditions. There is this mportant difference, however:—that the reduction of the temerature of the former to 60° or 50° is incompatible with the coninuance of their activity, which is only exhibited when the emperature rises to nearly the usual Mammalian standard;—vhilst a permanently low or moderate temperature is natural to the odies of most cold-blooded animals, whose functions could not be vell carried-on under a higher temperature. Thus all the muscles f a Frog are thrown into a state of permanent and rigid contracion, by the immersion of its body in water no warmer than the lood which naturally bathes those of the Bird; and we find, acordingly, that cold-blooded animals which cannot sustain a high emperature, are provided with a *frigorifying* rather than with a *alorifying* apparatus. Although we are accustomed to rank all nimals, save Birds and Mammals, under the general term *cold-looded*,, yet there exist among them considerable diversities as to he power of generating heat within themselves, and of thus renlering themselves independent of external variations. Thus mong Reptiles, it appears that there are some which can sustain temperature several degrees above that of the atmosphere, espeially when the latter is sinking; and among Fishes, it is certain hat there are species,—the *Thunny* and *Bonito* for example,—vhich are almost entitled to the name of warm-blooded animals, heir temperature being kept-up to nearly 100°, when that of the ea is about 80°. It is uncertain, however, to what extent it vould be depressed by a lowering of that of the surrounding melium. The greatest power of developing heat in cold-blooded nimals appears to exist when their bodies are reduced nearly to he freezing-point, and when that of the surrounding air or water s much below it. Thus Frogs have been found alive in the nidst of ice whose temperature was as low as 9°, the heat of their wn bodies being 33°; and it has been observed that even Aninalcules contained in water that is being frozen are not at once lestroyed, but that each lives for a time in a small uncongealed pace, where the fluid seems to be kept from solidifying by the aloric liberated from the Animalcule.

123. The peculiar condition of the class of Insects in regard to

its heat-producing power, exhibits in a very striking manner th connection between an elevated temperature and vital activity. I the *Larva* state of Insects the temperature of the animal follow closely that of the surrounding air, as in the cold-blooded class generally; but is usually from $\frac{1}{2}°$ to 4° above it. In the *Pup* condition, which is one of absolute rest in most insects that un dergo a complete metamorphosis, the temperature scarcely rise above that of the surrounding medium; except at nearly the clos of the period, when the creature is about to burst its envelop and to come-forth as the perfect Insect. The temperature whic different Insects possess in their *Imago* state, varies in part accor ing to the species, and in part with the condition of the individu in regard to rest or activity; but the same principle is evidentl operating in both cases, since the variation existing amongst diffe ent species in regard to their heat-producing power, is closel connected with the amount of activity natural to them. Th highest amount is to be found in the industrious Hive-Bee and i allies, and in the elegant and sportive Butterflies, which are a most constantly on the wing in search of food; next to these com the Beetles of active flight; and lastly those which seldom never raise themselves upon the wing, but pursue their labours c the ground. The temperature of individual Bees has been foun to be about 4° above that of the atmosphere when they are in state of repose; but it rises to 10° or 15° when they are excited t activity. When they are aggregated-together in clusters, howeve the temperature which they possess is often as much as 40° abov that of the atmosphere. When reduced to torpidity by cold, the still generate heat enough to keep them from being frozen, unle the cold be very severe; and they may be aroused by modera excitement to a state of activity, in which the temperature rises a very considerable elevation. Now although the increased pro duction of heat in these Insects, as in hybernating Mamma similarly aroused, is the *consequence* of the increased activity, the can be no question that it is a condition necessary to the *con tinuance* of that activity; since we find that if the temperatu of the body be again reduced by external cold, such activity car not be long maintained.

124. Whilst the foregoing facts exhibit the connection betwee an elevated temperature and the highest nervo-muscular activit in cold-blooded animals, there is abundant evidence of the sam kind in regard to the influence of Heat upon the processes of nu trition and development. Thus the time of emersion of Inse larvæ from their eggs,—or in other words, the rate at which th antecedent formative processes go-on, is essentially dependent upo the temperature to which the eggs have been exposed. In th case of the Bird, we find that if the temperature be not sufficie to develope the egg, chemical changes soon take-place which ir

volve the loss of its vitality; or if the temperature be reduced so low as to prevent the occurrence of those changes, the loss of heat is in itself destructive of life. But this is not the case in regard to the eggs of cold-blooded animals in general; for, like the beings they are destined to evolve, they may be reduced to a state of complete inactivity by a depression of the external temperature; whilst a slight elevation of this renews their vital operations, at a rate corresponding to the warmth supplied. Hence the production of larvæ from the eggs of Insects may be accelerated or retarded at pleasure; and this is, in fact, practised in the rearing of Silk-worms, in order to adapt the time of their emersion from the egg to that of the evolution of the leaves on which they feed. The same may be said in regard to the eggs of other cold-blooded animals; those, for example, of the minute Entomostracous Crustacea (Water-Fleas, &c.) which people our ditches and ponds. In many of these, the race is continued solely by the eggs, which remain dormant through the winter; all the parents being destroyed by the cold. The common *Daphnia pulex* produces two kinds of eggs; from one, the young are very speedily hatched; but the others, which are produced in the autumn and are enveloped in a peculiar covering, do not ordinarily give-birth to the young until the succeeding spring, though they may be at any time hatched by artificial warmth.

125. We sometimes find special provisions for imparting to the eggs a temperature beyond that which is natural to the bodies of the parents; thus in Serpents, the temperature of the posterior part of the body rises considerably when the eggs are lying in the oviduct preparatory to being discharged,—evidencing a special heat-producing power in the surrounding parts at this period, which is obviously for the purpose of aiding the maturity of the eggs. The Viper, whose eggs are frequently hatched in the maternal oviduct, so that the young are brought-forth alive, is occasionally seen basking in the sun, in such a position as to receive its strongest heat on the parts that cover the oviduct. Certain birds have recourse to substitutes for the usual method of incubation. The *Tallegalla* of New Holland is directed by its remarkable instinct, not to sit upon its eggs, but to bring them to maturity by depositing them in a sort of hot-bed, which it constructs of decaying vegetable matter. The Ostrich is believed to sit upon its eggs when the temperature falls below a certain standard, but to leave them to the influence of the solar heat when this is sufficient to bring them to maturity; and this statement derives confirmation from a similar fact observed in a Fly-catcher, which built in a hothouse during several successive years,—the bird quitting its eggs when the temperature was high, and resuming its place when it fell. In all these cases, as in many more which might be enumerated, we observe the influence of an

elevated temperature upon the processes of development; and we find a provision made by Nature, either in the physical or in the mental constitution of animals, for affording that influence. The development of heat around the oviduct of the Serpent is a process over which the individual has no control, being entirely dependent upon certain Organic changes; whilst the imparting of warmth to its eggs by the Bird, either from its own body or through artificial means, is committed to the guidance of its Instinct,—which same instinct leads it to suspend the process when it is not necessary.

126. Phenomena of an equally interesting and instructive character may be observed in the history of the Pupa-state of Insects; which, in those that undergo a complete metamorphosis, may be almost characterized as a re-entrance into the egg. In fact, we shall obtain the most correct idea of the nature of that metamorphosis, by considering the Larva as an embryo which comes-forth from the egg in a very early and undeveloped condition, for the sake of obtaining materials for its continued development which the egg does not supply in sufficient amount. When these have been digested and stored-up in the body, the animal becomes completely inactive, so far as regards its external manifestations of life; and it forms some kind of envelope for its protection, which may not be inaptly compared to the shell or horny covering of the egg. Within this are gradually developed the wings, legs, and other parts which are peculiar to the perfect Insect; whilst even those organs which it possesses in common with the Larva, are for the most part completely altered in character. When this process of development is completed, the Insect emerges from its Pupa case, just as the Bird comes-forth from the egg; then only does its Insect life begin, its previous condition having been that of a Worm; and the alteration of its character is just as evident in its instinctive propensities, as it is in its locomotive and sensorial powers.

127. Now this process of development is remarkably influenced by external temperature; being accelerated by genial warmth, and retarded by cold. There are many Larvæ which naturally pass into the Pupa state during the autumn, remain in it during the entire winter, and emerge as perfect Insects with the return of spring. It was found by Reaumur that Pupæ which would not naturally have been disclosed until May, might be called to undergo the metamorphosis during the depth of winter by the influence of artificial heat; whilst, on the other hand, their change might be delayed a whole year beyond its usual time by the prolonged influence of a cold atmosphere.—In order to hasten the development of the pupæ of the Social Bees, a very curious provision is made. There is a certain set to which the name of 'nurse-bees' has been given, whose duty it is to cluster over the

lls in which the 'nymphs' or Pupæ are lying, and to commucate to them the heat which is developed by the energetic ovements of their own bodies, and especially by respiratory tions of extreme rapidity. The 'nurse-bees' begin to crowd on the cells of the nymphs, about ten or twelve hours before ese last come-forth as perfect Bees. The incubation (for so it may called) is very assiduously persevered-in during this period by e 'nurse-bees;' when one quits the cell, another takes its place; d the rapidity of the respiratory movements increases until ey rise to 130 or 140 per minute, so as to generate the greatest iount of heat just before the young bees are liberated from the mbs. In one instance, the thermometer introduced among ven 'nurse-bees' stood at $92\frac{1}{2}°$; the temperature of the external r being 70°. We observe, in this curious propensity, a manifest ovision for accelerating the development of the perfect Insect, hich requires (as already pointed-out) a higher temperature than e larva, in virtue of its greater activity. The 'nurse-bees' do t station themselves over the cells which are occupied by the rvæ; nor do they incubate the nymph-cells with any degree of nstancy and regularity until the process of development is aproaching its highest point.

128. The influence of variations in the Heat of the body upon vital activity, is further manifested by the very remarkable periments of Dr. Edwards; who has shown that Cold-blooded imals *live much faster* (so to speak) at *high* temperatures than at w, so that they die much sooner when deprived of the requisite pply of oxygen.—Thus when *Frogs* were confined in a limited antity of water, and were not permitted to come to the surface breathe, it was found that the duration of their lives was inrsely proportional to the degree of heat of the fluid. When it is cooled-down to the freezing-point, the duration of the life of ogs immersed in it was from 367 to 498 minutes; at the temrature of 50°, this was from 350 to 375 minutes; at 72°, it was om 90 to 35 minutes; at 90°, from 12 to 32 minutes; and at 8°, death was almost instantaneous. The prolongation of life the lower temperatures is not due to torpidity, for the animals rform the functions of voluntary motion, and enjoy the use of eir senses; but it is occasioned by their diminished activity, iich occasions a less demand for air. On the other hand, the evation of temperature increases the demand for air, and causes eedier death when it is withheld, by increasing the general ility. The natural habits of these animals are in correspondence th these facts. During the winter, the influence of a sufficient iount of aërated water upon their exterior serves to maintain the quired amount of respiration through the skin, so that they are t obliged to come to the surface to take-in air by the mouth. the season advances, however, their activity increases, a larger

amount of respiration is required, and the animals are obliged to come frequently to the surface to breathe. During summer, the yet higher temperature calls-forth an increased energy and activity in all the vital functions; the respiration must be proportionably increased; the action of the air upon the cutaneous surface, as well as upon the lungs, is required; and if the animals be prevented from quitting the water to obtain this, they die as soon as the warmth of the season becomes considerable.—The result of experiments on *Fishes*, in regard to the deprivation or limited supply of the air contained in the water in which they are immersed, is exactly similar; the duration of life being inversely as the temperature. And precisely the same has been ascertained with respect to hybernating Mammals; which, as already remarked, are for a time reduced, in all such conditions, to the level of cold-blooded animals.

129. The energy of the *reparative* actions of Animals is much influenced by temperature, as might be inferred from what has been just said of their nutritive and developmental operations. Thus the rate at which regeneration of lost parts, as also that of the ordinary process of budding, takes-place in the common *Hydra* (fresh-water polype), is in close accordance with the temperature in which it lives; and in like manner, the healing of wounds in Frogs takes place more rapidly in summer than in winter. In many of the higher animals, indeed, it appears that the complete *regeneration* of parts requires a higher temperature than is necessary to sustain the ordinary vital activity. Thus it has been found that the common *Triton* (water-newt) can reproduce a limb that has been cut-off, if it be kept at a temperature of from 58° to 75°; but cannot do so if a less amount of heat be afforded to it. And in like manner, the Snail can regenerate its head if it be kept in a warm atmosphere, but not at a low temperature.—Now it has been justly remarked by Mr. Paget, that the process of *development* seems to require a higher amount of Vital force than simple *growth;* and we see that the relation already pointed-out between Heat and Vital force here holds-good in such a marked degree, as to afford a strong confirmation of the idea of their mutual relationship.

130. It is quite conformable to the same principle, that we should find Cold-blooded animals able to sustain the deprivation of food during a much longer period at low temperatures, than at high. The case is precisely the reverse, however, in regard to most Warm-blooded Animals; since in *them* a due supply of food is a condition absolutely necessary (as we have already seen) for the maintenance of that amount of bodily heat, whose loss is fatal to them; and exposure to a low temperature will of course more speedily bring-about that crisis. Hence it is that Cold and Starvation combined are so destructive to life. But in this respect

lso, the hybernating Mammals correspond with the cold-blooded lasses; their power of abstinence being inversely as the temperature of their bodies.

131. We have seen that the animals termed *cold-blooded* are reatly influenced as to the temperature of their bodies by the emperature of the surrounding medium; although many of them re endowed with the power of keeping themselves a certain umber of degrees above it. Now the consequence of this is, hat all of them which are subjected to any considerable and proonged amount of cold, pass into a state of more or less complete nactivity during its continuance; which state bears a close corespondence with the hybernation of certain Mammalia. Among he Reptiles of cold and temperate countries, this torpid state niformly occupies a considerable part of the year; as it does lso with Insects, terrestrial Mollusks, and other Invertebrated nimals, which are subject to the influence of the cold. On the ther hand, Fishes, Crustacea, and other marine animals, do not sually appear to pass into a state of torpidity; the temperature f the medium they inhabit never undergoing nearly so great a egree of depression as does that of the atmosphere.

132. The amount of change necessary to produce this effect, or n the other hand to call the animals from a state of torpidity to ne of active energy, differs for different species; and there is robably a considerable difference even among individuals of the ame species, according to the temperature under which they habitally live. Thus one animal may remain torpid under a degree f warmth which will be sufficient to arouse another of the same ind, accustomed to a somewhat colder climate; because the stiiulus is *relatively* greater to the latter. For example, it was bserved by Mr. Darwin, that at Bahia Blanca in South America, ie first appearance of activity in animal and vegetable life, a few ays before the vernal equinox, presented itself under a mean emperature of 58°, the range of the thermometer in the middle of ie day being between 60° and 70°. The plains were ornamented y the flowers of a pink wood-sorrel, wild peas, evening primoses, and geraniums; the birds began to lay their eggs; numeous beetles were crawling about; and lizards, the constant habitants of a sandy soil, were darting-about in every direction. et, a few days previously, it seemed as if nature had scarcely ranted a living creature to this dry and arid country; and it was nly by digging in the ground that their existence had been disovered,—several insects, large spiders, and lizards, having been und in a half-torpid state. Now at Monte Video, four degrees earer the Equator, the mean temperature had been above 58° for me time previously, and the thermometer rose occasionally uring the middle of the day to 69° or 70°; yet with this elevated mperature, nearly equivalent to the full summer heat of our

own country, almost every beetle, several genera of spiders, snails, and land-shells, toads and lizards, were still lying torpid beneath stones. From this example, we see how nicely the effective degree of stimulus is adapted to the general climate of the place, and how little relation it has to absolute temperature.

133. We may learn much from the Geographical distribution of the different species of cold-blooded animals, in regard to the influence of temperature on Animal life. No general inferences of this kind can be founded upon the distribution of warm-blooded animals; since their own heat-evolving powers make them in great degree independent of external warmth. It is probably from the distribution of the marine tribes, whose extension is least influenced by local peculiarities, that the most satisfactory deductions are to be drawn. In regard to the class of *Crustacea*, which is the one that has been most fully investigated in this respect, the following principles have been pointed-out by M. Milne-Edwards; they are probably more or less applicable to most others:—

I. Diversities of form and organization manifest themselves more, in proportion as we pass from the Polar Seas towards the Equator.

II. The differences of form and organization are not only more numerous and more characteristic in the warm than in the cold regions of the globe; they are also more important.

III. Not only are those Crustacea which are most elevated in the scale, deficient in the Polar regions; but their relative number increases rapidly as we pass from the Pole towards the Equator.

IV. When we compare together the Crustacea of different parts of the world, we observe that the average size of these animals is considerably greater in tropical regions than in the temperate or frigid climes.

V. It is where the species are most numerous and varied, and where they attain the greatest size,—in other words, where the temperature is most elevated,—that the peculiarities of structure which characterize the several groups are most strongly manifested.

VI. Lastly, there is a remarkable coincidence between the temperature of different regions, and the prevalence of certain forms of Crustacea.

134. Now although, as appears from the foregoing general statements, the number of *species* of Crustacea inhabiting the colder seas bears a very small proportion to that which is found within the tropics, and although the species formed to inhabit cold climates are so far inferior both as to size and as to elevation of development, yet it does not follow that the same proportion exists in regard to the relative amount of Crustacean life in the two regions; for this depends upon the multiplication of *individuals*. In fact, it may be questioned whether there is any inferiority in this respect; so abundant are some of the smaller

species in the Arctic and Antarctic, as well as in the Temperate seas. Thus we see that a low range of temperature is as well adapted to sustain *their* life, as a higher range is to call-forth those larger and more fully-developed forms which abound in the tropical ocean. There is an obvious reason why the *seas* of the frigid zones should be much more abundantly peopled than the *land;* the mean temperature of the former being much higher than that of the latter. And it would almost seem as if Nature had intended to compensate for the dreariness and desolation of the one, by the profuseness of life which she has fitted the other to support.

135. The influence of Temperature in producing a variation in the size of individual Animals of any one species, is not so strongly marked as it is in the case of Plants; for this reason, perhaps, that an amount of continued depression or elevation which might be sustained by a Plant, though it would exert a modifying influence upon its growth, would be fatal to an Animal formed to exist in the same climate. Instances are not wanting, however, in which such a modifying influence is evident; and these, as might be anticipated, are to be met-with chiefly among the cold-blooded tribes. Thus the *Bulimus rosaceus*, a terrestrial Mollusk, is found on the mountains of Chili of a size so much less than that which it attains on the coast, as to have been described as a distinct species. And the *Littorina petræa* found on the *south* side of Plymouth Breakwater, acquires, from its superior exposure to light and heat (though perhaps also from the greater supply of nutriment which it obtains) twice the size common to individuals living on the north side within the harbour.—The following circumstance shows the favourable influence of an elevated temperature in producing an unusual prolificness in Fish, which must be connected with an increase in general vital activity. Three pairs of Gold-fish were placed, some years since, in one of the engine-dams or ponds common in the manufacturing districts, into which the water from the engine is conveyed for the purpose of being cooled: the average temperature of such ponds is about 80°. At the end of three years, the progeny of these Fish, which were accidentally poisoned by verdigris mixed with the refuse tallow from the engine, were taken out by wheelbarrows-full. It is not improbable that the unusual supply of aliment furnished by the refuse grease that floats upon these ponds (which would impede the cooling of the water, if it were not consumed by the Fish), contributed with the high temperature to this unusual fecundity.

136. Although a very low temperature is positively inconsistent with the continuance of vital *activity*, in Animals as in Plants, yet we find that even very severe cold is not necessarily destructive of the vital *properties* of organized tissues; so that, on a restoration of the proper amount of heat, their functions may continue as

before. Of this we have already noticed an example in the case of frost-bitten limbs; but the fact is much more remarkable when considered in reference to the whole body of an animal, and to the complete suspension of all its functions. Yet it is unquestionably true, not only of the lowest and simplest members of the Animal kingdom, but also of Fishes and Reptiles. In one of Captain Ross's Arctic Voyages, several Caterpillars of the *Laria Rossii* having been exposed to a temperature of 40° *below zero*, froze so completely, that, when thrown into a tumbler, they clinked like lumps of ice. When thawed, they resumed their movements, took food, and underwent their transformation into the Chrysalis state; and one of them, which had been frozen and thawed four times, subsequently became a Moth. The eggs of the Slug have been exposed to a similar degree of cold, without the loss of their fertility. It is not uncommon to meet, in the ice of rivers and lakes, with Fishes which have been completely frozen, so as to become quite brittle, and which yet revive when thawed: marine fish, however, appear less capable of sustaining this change, to which they are of course far less likely to be subjected than are the inhabitants of small collections of water. The same thing has been observed in regard to Frogs, Newts, &c.; and the experiment of freezing and subsequently thawing them has been frequently put in practice. Spallanzani kept Frogs and Snakes in an ice-house for three years; at the end of which period they revived on being subjected to warmth.

137. It does not appear, however, that the like capability exists in the case of any warm-blooded animals; since if a *total* suspension* of vital activity take place in the body of a Bird or Mammal for any length of time, in consequence of the prolonged application of severe cold, recovery is found to be impossible. The power which exists in these animals, however, of generating a large amount of heat within their bodies, acts as a compensation for the want of the faculty possessed by the cold-blooded tribes; since they can resist for a great length of time (if in their healthy or normal condition) the depressing influence of a temperature sufficiently low to produce a complete suspension in the activity of the latter.

138. It only remains to say a few words regarding the degree of *heat* which certain Animals can sustain without prejudice, and which even appears to be congenial to them. Among the higher classes, this range *seems* to be capable of great extension. Thus many instances are on record, of a heat of from 250° to 280° being endured, in dry air, for a considerable length of time without much inconvenience; and persons who have become habituated to

* In the case of hybernating Mammals, the suspension is not total; and if it be rendered such, the same result follows as in other instances.

this kind of exposure, can (with proper precautions) sustain a temperature of from 350° to 500°. In all such cases, however, the real heat of the body undergoes very little elevation; for, by means of the copious evaporation from its surface, the external heat is prevented from acting upon it. But if this evaporation be prevented, either by an insufficiency in the supply of fluid from within, or by the saturation of the surrounding air with moisture, the temperature of the body begins to rise; and it is then found that it cannot undergo an elevation of more than a few degrees without fatal consequences. Thus in several experiments which have been tried on different species of warm-blooded animals, for the purpose of ascertaining the highest temperature to which the body could be raised without the destruction of life, it was found, that, as soon as the heat of the body had been increased by continued immersion in a limited quantity of hot air (which would soon become charged with moisture) to 9°—13° above the natural standard, the animals died. In general, Mammals die when the temperature of their bodies is raised to about 111°, the heat which is natural to the bodies of Birds. The latter also are killed by an equal elevation of their bodily heat above its natural standard.

139. Hence we see that the actual range of temperature within which vital activity can be maintained in all such warm-blooded animals as do not hybernate, is extremely limited; a temporary elevation of the heat of the body to 13° above its natural standard, or a depression to 30° below, being positively inconsistent not merely with the continuance of its vital operations, but also with the preservation of its vital properties; and a continued departure from that standard, to the extent of only a very few degrees above or below it, being very injurious. The provisions with which these animals are endowed for generating *heat* in their interior, so as to supply the external deficiency, and for generating *cold* (so to speak) when the external temperature is too high, are therefore in no respect superfluous: but are positively necessary for the maintenance of the life of such animals in any climate, save one whose *mean* should be conformable to their standard, and whose *extremes* should never vary more than a very few degrees above or below it. Such a climate does not exist on the surface of the earth.

140. The range of *external* temperature within which cold-blooded animals can sustain their activity, is much more limited, in regard as well to its highest as to its lowest point; notwithstanding that the range of *bodily* heat which is consistent with the maintenance of their life, is so much greater. In those which, like the Frog, have a soft moist skin, which permits a copious evaporation from the surface, a considerable amount of heat may be resisted, provided the air be dry, and the supply of fluid from

within be maintained.* But immersion in water of the temperature of 108° is almost immediately fatal. In many other cold-blooded animals, elevation of the temperature induces a state of torpidity, analogous to that which is produced by its depression. Thus the *Helix pomatia* (edible snail) has been found to become torpid and motionless in water at 112°, but to recover its energy when placed in a colder situation. It would seem to be partly from this cause, but partly also from the deprivation of moisture, that the *hottest* part of the tropical year brings-about a cessation of activity in many tribes of cold-blooded animals, as complete as that which takes-place during the *winter* of temperate climates.

141. The highest limit of temperature compatible with the life of Fishes has not been certainly ascertained: and it appears probable that there are considerable variations in this respect amongst different species. Thus it is certain that there are some which are killed by immersion in water at 104°; whilst it is also certain that others can not only exist, but can find a congenial habitation, in water of 113°, or even of 120°; and examples of the existence of Fishes in thermal springs of a much higher temperature than this have been put on record. Various fresh-water Mollusks have been found in thermal springs, the heat of which is from 100° to 145°. Rotifers and other Animalcules have been met-with in water at 112°. Larvæ of Tipulæ have been found in hot springs of 205°; and small black Beetles, which died when placed in cold water, in the hot sulphur baths of Albano. Entozoa inhabiting the bodies of Mammalia and of Birds must of course be adapted to a constant temperature of from 98° to 110°; and they become torpid when exposed to a cool atmosphere. These lowly-organized animals seem more capable of resisting the effects of extreme heat than any others; at least if we are to credit the statement that the Entozoa inhabiting the intestines of the Carp have been found alive, when the Fish was brought to table after being boiled.—In all such cases, it is to be remembered that the heat of the animal body must correspond with that of the fluid in which it is immersed; and we have here, therefore, evident proof of the compatibility of vital activity, in certain cases, with a very elevated temperature. Additional and more exact observations, however, are much wanting on this subject.

* The Frog has a remarkable provision for this purpose, in a bladder which is *structurally* analogous to our Urinary bladder, but which has for its chief function to contain a store of fluid for the exhaling process. It has been noticed, that, when this store has been exhausted by continued exposure of the animal to a warm dry atmosphere, the bladder becomes full again when the animal is placed in a moist situation, even though it should take-in no liquid by its mouth.

3. *Of Electricity, as a Condition of Vital Activity.*

142. Much less is certainly known with respect to the ordinary influence of this agent, than in regard to either of the two preceding; and yet there can be little doubt, from the effects we observe when Electricity is powerfully applied, as well as from our knowledge of its connexion with all Chemical phenomena, that it is in constant though imperceptible operation. Electricity differs from both Light and Heat in this respect; — that no manifestation of it takes place so long as it is uniformly diffused, or is in a state of *equilibrium;* but in proportion as this equilibrium is disturbed by a change in the electric condition of one body, which is prevented, by its partial or complete insulation, from communicating itself to others, in that proportion is a *force* produced, which exerts itself in various ways according to its degree. The *mechanical* effects of a powerful charge, when passed through a substance that is a bad conductor of Electricity, are well known; on the other hand, the *chemical* effects of even the feeblest current are equally obvious. The agency of Electricity in producing Chemical change is the more powerful, in proportion as there is already a predisposition to that change; thus, the largest collection of oxygen and hydrogen gases, or of hydrogen and chlorine, mingled together, may be caused to unite by the minutest electric spark, which brings into the condition required for their active exercise the mutual affinities that were previously dormant. Hence it cannot but be inferred, that its agency in the Chemical phenomena of living bodies must be of an important character; but this may probably be exerted rather in the way of aiding decomposition, than in producing new combinations, to which (as we have seen) Light appears to be the most effectual stimulus. Thus it has been shown, that pieces of meat which have been electrified for some hours, pass much more rapidly into decomposition than similar pieces placed under the same circumstances but not electrified. And in like manner, the bodies of animals that have been killed by electric shocks, lose their vital endowments and pass into the putrescent state much more readily than those of similar animals killed by an injury to the brain. It is well known, moreover, that in thundery weather, in which the electric state of the atmosphere is much disturbed, various fluids containing albuminous compounds, such as milk, broth, &c., are peculiarly disposed to turn sour; and that saccharine fluids, such as the wort of brewers, are extremely apt to pass into the acetous fermentation.

143. The actual amount of influence, however, which Electricity exerts over a growing Plant or animal, can scarcely be estimated. It would, perhaps, be the most correct to say, that the state of Electric *equilibrium* is that which is generally most favour-

able; and we find that there is a provision in the structure of most living beings for maintaining such an equilibrium, — not only between the different parts of their own bodies, but also between their own fabrics and the surrounding medium. Thus a charge given to any part of a Plant or Animal, is immediately diffused through its whole mass; and though Organized bodies are not sufficiently good conductors to transmit very powerful shocks without being themselves affected, yet a discharge of any moderate quantity may be effected through them without any permanent injury, — and this more especially if it be made to take place slowly. Now the points on the surfaces of Plants appear particularly adapted to effect this transmission: thus a Leyden jar may be discharged by holding a blade of grass near it, in one-third of the time required to produce the same effect by means of a metallic point; and an Electroscope furnished with Vegetable points has been found to give more delicate indications of the electric state of the atmosphere than any other. Plants designed for a rapid growth have generally a strong pubescence or downy covering; and it does not seem improbable that one purpose of this may be to maintain that equilibrium between themselves and the atmosphere, which would otherwise be disturbed by the various operations of vegetation, and especially by the process of evaporation, which takes-place with such activity from the surface of the leaves.

144. There appears to be sufficient evidence, that, during a highly electric state of the atmosphere, the growth of the young shoots of certain plants is increased in rapidity; but it would be wrong thence to infer, that this excitement is useful to the process of Vegetation in general, or that the same kind of electric excitement universally operates to the benefit or injury of the Plant. From some experiments made a few years since, it would appear that potatoes, mustard and cress, cinerarias, fuchsias, and other plants, have their development, and, in some instances, their productiveness, increased by being made to grow between a copper and a zinc plate, connected by a conducting wire; while, on the other hand, geraniums and balsams are destroyed by the same influence. The transmission of a series of moderate sparks through plants, in like manner, has been found to accelerate the growth of some, and to be evidently injurious to others. It is not unreasonable to suppose, that, as a great variety of chemical processes are constantly taking place in the growing plant, an electric disturbance, which acts as a stimulus to some, may positively retard others; and that its good or evil results may thus depend upon the balance between these individual effects. This would seem the more likely from the circumstance, that, in the process of Germination, the chemical changes concerned in which are of a simpler character, Electricity seems to have a more decided and

niform influence. The conversion of the starch of the seed into ıgar, which is an essential part of this change, involves the beration of a large quantity of carbonic and of some acetic acid. Tow as all acids are negative, and as like electricities repel each ther, it may be inferred, that the seed is at that time in an electro-egative condition; and it is accordingly found that the process of ermination may be quickened by connexion of the seed with the egative pole of a feeble galvanic apparatus, whilst it is retarded by similar connexion with the positive pole. A similar acceleration ıay be produced by the contact of feeble alkaline solutions, which ıvour the liberation of the acids; whilst, on the same principle, very small admixture of acid in the fluid with which the seed s moistened, is found to produce a decided retardation.

145. It is well known that Trees and Plants may be easily illed by powerful electric shocks; and that, when the charge is trong enough (as in the case of a stroke of lightning), violent nechanical effects,—as the rending of trunks, or even the split-ing and scattering of minute fragments,—are produced by it. But it has also been ascertained that charges which produce no perceptible influence of this kind may destroy the life of Plants, hough the effect is not always immediate: in particular it has been noticed that slips and grafts are prevented from taking root ınd budding. There can be little doubt that, in these instances, change is effected in the chemical state of the fluids, although no structural alteration be perceptible.

146. In regard to the influence of Electricity upon the Organic unctions of Animals, still less is certainly known; but there is evidence that it may act as a powerful stimulant in certain dis-ordered states of them. Thus in Amenorrhœa, a series of slight but rapidly-repeated electric shocks will often bring-on the cata-menial flow; and it is certain that chronic tumours have been dispersed, and dropsies relieved by the excitement of the absorb-ent process, through similar agency. In fact, there is strong reason to believe, that Electricity may be advantageously employed remedially in many states of disordered nutrition; in virtue of ts power of modifying the operations of the Vital forces.

147. The closest relations of Electricity, however, are with the proper Animal functions; for these, as will be shown hereafter, are more directly and obviously subject to its influence than are the Organic. Thus Electricity, when transmitted along a Nerve, whether sensory or motor, a nerve of 'special' or one of 'common' sensation, is capable of calling-forth all the actions of which that nerve is the instrument; and when brought to bear on a Muscle, it immediately excites a contractile movement.—It is probably through the influence of this agent upon the Nervous System, that electric states of the atmosphere induce in certain individuals a degree of languor and depression, which cannot be

accounted-for in any other way. An instance is on record, in which the atmosphere was in such an extraordinary state of electric disturbance, that all pointed bodies within its influence exhibited a distinct luminosity; and it was noticed that all the persons who were exposed to the agency of this highly-electrified air, experienced spasms in the limbs and an extreme state of lassitude.

148. Animals, like Plants, are liable to be killed by shocks of Electricity, even when these are not sufficiently powerful to occasion any *olvious* physical change in their structure. But, as formerly mentioned (§ 68), there can be no doubt that minute changes may be produced in their delicate parts, which are quite sufficient to account for the destruction of their vitality, even though these can only be discerned with the Microscope. The production of changes in the Chemical arrangement of their elements, is, however, a much more palpable cause of death; since it may be fully anticipated beforehand, and can easily be rendered evident. To take one instance only;—it is well known, that *albumen* is made to coagulate, *i. e.*, is changed from its soluble to its insoluble form, under the influence of an electric current; and it cannot be doubted that the production of this change in the fluids of the living body (almost every one of which contains albumen), though to a very limited extent, is quite a sufficient cause of death, even in animals that are otherwise most tenacious of life. "I once discharged a battery of considerable size," says Dr. Hodgkin, "through a common Earth-worm, which would in all probability have shown signs of life long after minute division. Its death was as sudden as the shock; and the semi-transparent substance of the animal was changed like Albumen which has been exposed to heat."

4. *Of Moisture, as a Condition of Vital Activity.*

149. Independently of the utility of Water as an article of *food*, and of the part it performs in the Chemical operations of the living body by affording two of their most important materials (oxygen and hydrogen), there can be no doubt that a certain supply of moisture is requisite as one of the conditions without which no vital actions can go-on. It has been already remarked, indeed, that one of the distinguishing peculiarities of Organized structures is the presence of solid and liquid component parts; and this in the minutest portions of the organism, as well as in the aggregate mass. And in all the *vital*, as well as in the *chemical* actions, to which these structures are subservient, the presence of liquid is essential. All nutrient materials must be reduced to the liquid form, before they can be assimilated by the solids; and, again, the solid matters which are destined to be carried-off by

cretion, must be again reduced to the liquid state before they n be thus withdrawn from the body. The tissues in which the ost active changes of a purely vital character are performed, — mely, the Nervous and Muscular, — naturally contain a very rge proportion of water; the former as much as 79, and the tter 75 per cent. On the other hand, in tissues whose function of a purely-mechanical nature, such as Bone, the amount liquid is as small as is consistent with the maintenance of certain amount of nutrient action in its interior. By the ng-continued application of dry heat to a dead body, its weight as found to be reduced from 120 pounds to no more than 12; so at taking the average of the whole, the amount of Water ot chemically combined but simply interstitial might be reckoned as much as 90 per cent. It is certain, however, that much de- mposition and loss of solid matter must have taken-place in this ocedure; and we shall probably estimate the proportion more curately, if we regard the weight of the water of the Human ody as between two-thirds and three-fourths of the whole.

150. There is a great variation in this respect, however, among fferent tribes of living beings. There are probably no highly ganized Animals whose texture contains *less* liquid than that of ertebrata (unless it may be certain Beetles); but there can be no uestion that, among some of the Zoophytes, the proportion of lids to liquids is just the other way. In those massive coral- rming animals, which seem to have been expressly created for e purpose of uprearing islands and even continents from the epths of the ocean, we find the soft tissues confined to the sur- ce, and all within of a rocky hardness. It is not, however, cor- ect to say (as is commonly done), that the coral polypes 'build p' these stony structures as habitations for themselves; for the ony matter is deposited by an act of nutrition in the living ssue of these animals, just as much as it is in the bones of Man. ut the parts once consolidated henceforth remain almost dead, so r as the animal is concerned; they are not connected with the ving tissues by any vessels, nerves, &c.; their density prevents em from undergoing any but a very slow change, so that they equire and receive scarcely any nutrient materials; and they ight be altogether removed by accident or decay, without any irect injury to the still active because yet unconsolidated por- ons of the polype-structure.

151. There is a close correspondence in this respect, between e condition of the stony or horny stem of a Coral, and the heart- ood of the trunk of a tree; for the latter, becoming consolidated y internal deposit for the purpose of affording mechanical sup- ort, is thenceforth totally unconnected with the vegetative opera- ons of the tree, and might be removed (as it frequently is by atural decay) without affecting them. In all the parts in which e nutrient processes are actively going-on, do we observe that

the tissue contains a large proportion of water; and that if succulent portions be dried-up, their vital properties are destro Thus it is in the soft tissue at the extremities of the radicle root-fibres, that the function of absorption is performed with greatest activity; so that these parts have received the nam *spongioles:* it is in the cells which form the soft parenchym the leaves, that the elaboration of the sap, the fixation of ca from the atmosphere, and the preparation of the peculiar secret of the plant take-place: and it is in the space between the l and the wood, which is occupied (at the season of most ac growth) by a saccharine glutinous fluid, that the formation of new layers of wood and bark is effected. Now as soon as t parts become consolidated, they cease to perform any active operations. The spongioles, by the lengthening of the root-fi become converted into a portion of those fibres, and remain s servient merely to the transmission of the fluids absorbed; leaves gradually become choked by the saline and earthy parti contained in the ascending sap, which they have had no powe excreting, and they wither, die, and fall-off; and the new la of wood and bark, when once formed, undergo but little fur change, and are subservient to little else than the transmissio the ascending and descending sap to the parts where they ar be respectively appropriated.

152. There are some remarkable instances in both the Ani and Vegetable kingdoms, of an immense preponderance in amount of the fluids over that of the solids of the structure. T is characteristic of the whole group of *Acalephæ* or 'jelly-fi giving to their tissues that softness from which their comr name is derived; these animals, in consequence, are unable to out of water; for when they are removed from it, a drain of t fluids commences, which soon reduces their weight to a deg that destroys their lives,—a Medusa weighing fifty pounds be thus dried-down to a weight of as many grains. The most rema able instances of a parallel kind among Plants, are to be founc the tribe of *Fungi;* certain members of which are distinguis by an almost equally small proportion of solid materials in t textures, presenting a most delicate gossamer-like appearance the eye, and possessing such little durability that they come maturity and undergo decay in the course of a few hours. Th are not inhabitants of the water, but will vegetate only in a v damp atmosphere.

153. As we find various Plants and Animals very differen constructed in regard to the amount of fluid contained in th tissues, so do we also find them dependent in very different degr upon a constant supply of external moisture. There is no relati however, between the succulence of a plant, and the degree of dependence upon water; in fact, we commonly find the m

cculent plants growing in the driest situations; whilst the plants hich are adapted to localities where they can obtain a constant pply of fluid, are not usually remarkable for the amount of ater in their own structure. This, however, is easily explained. e find the most succulent plants,—such as the *Sedums* or 'stone-ops' of our own country, and the *Cacti* and *Euphorbiæ* of the opics,—in dry exposed situations, where they seem as if they ould be utterly destitute of nutriment. The fact is, however, at they lose their fluid by exhalation very slowly, in consequence their small number of stomata; whilst, on the other hand, they sorb with great readiness during rainy weather, and are enabled, the fleshiness of their substance, to store-up a large quantity moisture until it may be required. In some parts of Mexico, e heat is so intense, and the soil and atmosphere so dry, during large part of the year, that no vegetation is found at certain asons, save a species of Cactus; this affords a wholesome and freshing article of food, on which travellers have been able to ibsist for many days together, and without which these tracts ould form impassable barriers. On the other hand, the plants of amp situations usually exhale moisture almost as fast as they nbibe it; and consequently, if their usual supply be cut-off or iminished, they soon wither and die. Plants that usually live ntirely submerged, are destitute of the cuticle or thin skin which overs the surface in other cases; in consequence of this, they ery rapidly lose their fluid when they are removed from the ater; and they are hence dependent upon constant immersion in t for the continuance of their lives, although their tissues may ot be remarkable for the amount of fluid which they contain.

154. There are some Plants which are capable of adapting hemselves to a great variety of situations, differing widely as to he amount of moisture which their inhabitants can derive from he soil and atmosphere; and we may generally notice a marked ifference in the mode of growth, when we compare individuals hat have grown under opposite circumstances. Thus a plant rom a dry exposed situation shall be stunted and hairy, whilst nother, of the same species, but developed in a damp sheltered ituation, shall be rank and 'glabrous' (smooth). But in general here is a certain quantity of moisture congenial to each species; nd the excess or deficiency of this condition has, in consequence, s great an influence in determining the geographical distribution f Plants, as the amount of light and heat. Thus, as already emarked, the Orchideæ and Tree Ferns of the Tropics grow best n an atmosphere loaded with dampness; whilst the Cactus tribe, or the most part, flourishes best in dry situations. The former ecome stunted and inactive, if limited in their supply of aërial noisture; whilst the latter, if too copiously nourished, become ropsical and liable to rot. Among the plants of our own country

we find a similar limitation; a moist boggy situation being indispensable to the growth of some, whilst a dry exposed elevation is equally essential to the healthy development of others. There is a beautiful species of exotic Fern, the *Trichomanes speciosum*, the rearing of which has been frequently attempted in this country and elsewhere, without success; but which only requires an atmosphere saturated with dampness for its healthy development, being easily grown in one of Mr. Ward's closed glass-cases. In this, as in similar examples, it is only necessary to imitate as closely as possible the conditions under which the species naturally lives; and sometimes this can only be accomplished by surrounding the plant with small trees and shrubs, so as to give it a moister atmosphere than it could otherwise attain. Professor Royle mentions the growth, under such circumstances, of a fine specimen of the *Xanthochymus dulcis*, one of the *Guttiferæ* or Gamboge-trees, in the garden of the King of Delhi; this tree is naturally found only in the southern parts of India; and the success of its cultivation in this northerly situation was entirely due to its being sheltered by the numerous buildings within the lofty palace-wall, surrounded by almost a forest of trees, and receiving the benefit of perpetual irrigation from a branch of the canal which flows through the garden.

155. In regard to the influence of external moisture upon Animal life, there is much less to be said; since the mode in which fluid is received into the system is so entirely different. It may be remarked, however, that Animals habitually living beneath the water, like submerged Plants, are usually incapable of sustaining life for any length of time when removed from it, in consequence of the rapid loss of fluid which they undergo from their surface. It is, however, by the desiccation of the *respiratory* surface, preventing the due aëration of blood, that the final result is for the most part occasioned; since we find, that when there is a special provision to prevent this, as in the case of certain Fishes and Crustacea, the animals can quit the water for a great length of time. There can be no doubt that the amount of Atmospheric moisture is one of those conditions which are collectively termed 'climate,' and which influence the geographical distribution of Animals no less than that of Plants; but it is difficult to say how far the variations in moisture act alone. Every one, however, is conscious of the effect upon his health and spirits, of such variations as take place in the climate he may inhabit. The two principal modes in which these seem to operate will be by accelerating or checking the exhalation of fluid from the Skin and from the Pulmonary surface; for when the air is already loaded with dampness, the exhaled moisture cannot be carried off with the same readiness as when it is in a condition of greater dryness; and it will consequently either remain within the system, or it will

cumulate and form sensible perspiration. It can scarcely be nsidered improbable, however, that the influence of moisture on e conducting power of the atmosphere for Electricity, has something to do with its peculiar influence on the state of the nervous stem.

156. Now each of these states may be salutary, being the one st adapted to particular constitutions, or to different states of e same individual. A cool drying wind shall be felt as invigorating to the relaxed frame, as it is chilling to one that has no warmth moisture to spare; on the other hand, a warm damp atmosphere ich is refreshing to the latter, shall be most depressing to the mer. All who have tried the effect of closely-fitting garments pervious to moisture are well aware how oppressive they soon come; this feeling being dependent upon the obstruction they casion to the act of perspiration, by causing the included air to speedily saturated with moisture. When the fluids of the stem have been diminished in amount, either by the suspension a due supply of water, or by an increase in the excretions, there a peculiar refreshment in a soft damp atmosphere, or in a warm th, which allows the loss to be replaced by absorption through e general cutaneous surface. The reality of such absorption has en placed beyond all doubt by observations upon men who had en exposed to a hot dry air for some time, and were afterwards ced in a warm bath; for it was found that the system would, this unusual means, supply the deficiency which had been eated by the previous increase in the transpiration.

157. The effect of a moist or dry atmosphere, then, upon the imal body, cannot be by any means unimportant; although, as e shall hereafter see, there exists in it a series of the most remarkable provisions for regulating the amount of its fluids. The fluence of atmospheric moisture, however, is most obvious in sordered states of the system. Thus in persons who are subject the form of Dyspepsia called atonic, which is usually connected th a generally-relaxed condition of the system, a very perceptible fluence is experienced from changes in the quantity of atmospheric moisture; the digestive power, as well as the general nctions of the body, being invigorated by dryness, and depressed damp. Again there is no doubt that where a predisposition ists to the Tuberculous Cachexia, it is greatly favoured by bitual exposure to a damp atmosphere, especially when accomnied by cold: indeed it would appear, from the influence of ld damp situations upon animals brought from warmer climates, at these two causes may induce the disease in individuals preously healthy. On the other hand, there are some forms of lmonary complaints, in which an irritable state of the mucous embrane of the bronchial tubes has a large share; when this itation presents itself in the *dry* form, a warm moist atmos-

phere is found most soothing to it; whilst a drier and more bracing air is much more beneficial, when the irritation is accompanied by a too copious secretion.

158. Although, as already stated, no vital actions can go-on without a reaction between the *solids* and *fluids* of the body, yet there may be an entire loss of the latter, in certain cases, without necessarily destroying life; the structure being reduced to a state of dormant vitality in which it may remain unchanged for an unlimited period, and yet being capable of renewing all its actions when moisture is again supplied. Of this we find numerous examples among both the Vegetable and the Animal kingdoms. Thus the Mosses and Liverworts which inhabit situations where they are liable to occasional drought, do not suffer from being (to all appearance) completely dried up, but revive and vegetate actively as soon as they have been thoroughly moistened. Instances are recorded in which Mosses that have been for many years dried-up in a Herbarium, have been restored by moisture to active life. There is a *Lycopodium* (club-moss) inhabiting Peru, which, when dried-up for want of moisture, folds its leaves and contracts into a ball; and in this state, apparently quite devoid of animation, it is blown hither and thither along the surface by the wind: as soon, however, as it reaches a moist situation, it sends-down its roots into the soil, and unfolds to the atmosphere its leaves, which, from a dingy brown, speedily change to the bright green of active vegetation. The *Anastatica* (rose of Jericho) is the subject of similar transformations; contracting into a ball, when dried-up by the burning sun and parching air; being detached by the wind from the spot where its slender roots had fixed it, and rolled over the plains to indefinite distances; and then, when exposed to moisture, unfolding its leaves, and opening its rose-like flower, as if roused from sleep. A blue Water-Lily abounds in several of the canals at Alexandria, by the drying-up of which at certain seasons, their beds are burnt as hard as bricks by the action of the sun, so as to be fit for use as carriage-roads; yet the plants do not thereby lose their vitality, for when the water is again admitted they resume their growth with redoubled vigour.

159. Among the lower Animals, we find several of considerable complexity of structure, which are able to sustain the most complete desiccation. This is most remarkably the case in the common *Wheel-Animalcule;* which may be reduced to a state of most complete dryness, and kept in this condition for any length of time, and which will yet revive immediately on being moistened. The same individuals may be treated in this manner, over and over again. Experiments have been carried still further with the allied tribe of *Tardigrades;* individuals of which have been kept in a vacuum for thirty days, with sulphuric acid and chloride of

alcium (thus suffering the most complete desiccation the Chemist an effect), and yet have not lost their vitality. It is singular hat in this desiccated condition, they may be heated to a temerature of 250° without the destruction of their lives; although, rhen in full activity, they will not sustain a temperature of more han from 112° to 115°. Some of the minute Entomostracous 'rustacea, which are nearly allied to the Rotifera, appear to parake with them in this curious faculty. Many instances are on ecord, in which Snails and other terrestrial Mollusks have reived after what appeared to be complete desiccation; and the *ggs* of the Slug, when dried-up by the sun or by artificial heat, nd reduced to minute points only visible with the Microscope, re found not to have lost their fertility, when they are moistened y a shower of rain or by immersion in water, which restores hem to their former plumpness. Even after being treated eight imes in this manner, such eggs have been hatched when placed a favourable circumstances; and even eggs in which the embryo ras distinctly formed, survived such treatment without damage.—'hat such capability should exist in the animals and eggs just nentioned, shows a remarkable adaptation to the circumstances a which they are destined to exist; since, were it not for their ower of surviving desiccation, the races of Wheel-Animalcules nd Entomostraca must speedily become extinct, through the eriodical drying-up of the small collections of water which they ahabit; and a season of prolonged drought must be equally fatal o the terrestrial Mollusca.

160. It would seem, that many cold-blooded animals are reduced y a moderate deficiency of fluid to a state of torpidity closely esembling that induced by cold; and hence it is, that during the ottest and driest part of the tropical year there is almost as omplete an inactivity as in the winter of temperate regions. The ommon Snail, if put into a box without food, constructs a thin perculum or partition across the orifice of the shell, and attaches tself to the side of the box; in this state it may remain dormant or years without being affected by any ordinary changes of temerature, but it will speedily revive if plunged in water. Even a their natural haunts, the terrestrial Mollusks of our own climates re often found in this state during the summer when there is a ontinued drought; but with the first shower they revive and nove about. In like manner, it is observed that the rainy season etween the tropics brings-forth the hosts of Insects which the rought had caused to remain inactive in their hiding-places. nimals rendered torpid by deficiency of moisture seem to have a endency to bury themselves in the ground, like those which are riven to winter-quarters by cold. Mr. Darwin mentions that he bserved with some surprise at Rio de Janeiro, that, a few days fter some little depressions had been changed into pools of water

by the rain, they were peopled by numerous full-grown shells and beetles.

161. This torpidity consequent upon drought is not confined to Invertebrated animals. There are several Fish inhabiting fresh water, which bury themselves in the mud when the streams or pools are dried-up, and which remain there in a torpid condition until they are again moistened. This is the case with the curious *Lepidosiren*, which forms so remarkable a connecting link between Fishes and the Batrachian Reptiles: it is an inhabitant of the upper parts of the river Gambia, which are liable to be dried-up during much more than half the year; and the whole of this period is spent by it in a hollow which it excavates for itself deep in the mud, where it lies coiled-up in a completely torpid condition,—whence it is called by the natives the 'sleeping-fish.' When the return of the rainy season causes the streams to be again filled, so that the water finds its way down to the hiding-place of the Lepidosiren, it comes-forth again for its brief period of activity; and with the approach of drought, it again works its way down into the mud, which speedily hardens around it into a solid mass. In the same manner, the *Proteus* (§ 670), when the underground lakes it inhabits are periodically dried-up, retires to the passages that connect them, where it is believed to remain in a torpid condition; and it thence emerges into the lakes, as soon as they again become filled with water. The Lizards and Serpents, too, of tropical climates, appear to be subject to the same kind of torpidity in consequence of drought, as that which affects those of temperate regions during the cold of winter. Thus Humboldt has related the strange accident of a hovel having been built over a spot where a young Crocodile lay buried, alive though torpid, in the hardened mud; and he mentions that the Indians often find enormous Boas in the same lethargic state, and that these revive when irritated or wetted with water.—All these examples show the necessity of a fixed amount of fluid, in the Animal structure, for the maintenance of vital *activity:* whilst they also demonstrate that the preservation of the vital *properties* of that structure is not always incompatible with the partial, or even the complete, abstraction of that fluid; the solid portions being then much less liable to decomposition by heat, or by other agencies, than they are in the ordinary condition.

CHAPTER III.

COMPONENT MATERIALS OF THE ANIMAL FABRIC.

1. *Ultimate Elements.*

162. The body of Man, as of any other Organized being, if educed by ultimate analysis to its most simple components, would e found to consist entirely of elementary substances which are bundant in the World around; this being, in fact, a necessary onsequence of the essential conditions of its existence. For we nd that (1) it is built-up from the germ, in the first instance, at he expense of materials which it draws from sources external to self; (2) it is continually drawing into itself, during the whole ourse of its life, fresh supplies of similar material; (3) it is as onstantly discharging from itself an equivalent amount of the ame ultimate elements united together in simpler forms, the omposition of the body remaining nearly unaltered for long eriods of time, notwithstanding the perpetual change of its constituent particles; and (4) that when its integrity is destroyed by ost-mortem decay, its component materials are all restored to the xternal World, in forms which make them ready to recommence the ame cycle as that which they have already gone through (§ 15).

163. Of all the non-metallic elements of the Animal body, *)xygen* is by far the most conspicuous in amount; since it not nly constitutes eight-ninths of the Water which forms (in Man) t least two-thirds of its entire weight; but also about a fourth part f the Albuminous and Gelatinous compounds which constitute he chief basis of its solids, and about one-tenth part of its Fat. *Iydrogen*, on the other hand, not only constitutes as little as oneinth of the Water of the body; but contributes no more than 7 er cent. to the weight of the Albuminous and Gelatinous tissues; 'hilst even Fat, which is proportionally richer in this element han any other Organic Compound, contains only 10 per cent. of . Of the solids of the body taken by themselves, however, *'arbon* forms the largest part; since it constitutes more than *onealf* of the weight of the Albuminous and Gelatinous compounds, nd nearly *three-fourths* of that of Fat. Lastly, *Nitrogen*, which oes not exist in Fat, forms about one-sixth of the weight of 1e Albuminous and Gelatinous compounds. Of the other non-1etallic elements the most abundant is *Phosphorus;* which seems) be an essential constituent of the Albuminous and Gelatinous ompounds, and is peculiarly abundant in nervous substance; and 'hich, combined with oxygen and calcium into Phosphate of Lime of which it constitutes 20 per cent.), is universally present in the olids and fluids of the animal body, but is specially abundant in 1e bony skeleton, the solidity of which depends on its presence.

Sulphur, also, is very intimately united with the other components of the Albuminous and Gelatinous tissues; and in combination with oxygen and alkaline bases, forming sulphates, it is generally present in small quantity in the fluids; this combination having reference apparently to its ready elimination from the system in the condition of a soluble salt. Another non-metallic element very generally diffused through the system is *Chlorine;* its compound with sodium being an almost universal and apparently essential constituent of the solids and fluids of the body.

164. Of the Metallic bases, the one that occurs most largely in the Animal fabric is *Calcium;* which is not only very generally diffused in small quantity through the fluids and softer tissues, but is the principal solidifying material of the skeleton. Putting aside the skeleton, however, we find *Sodium* to be the metallic base most largely as well as universally present in the several parts of the animal body; being diffused through its fluids, as well as a nearly constant component of its solids. But in the substance of the Muscles, and in the red corpuscles of the Blood, the place of sodium is in great degree taken by *Potassium*; and this base also presents itself, though in smaller proportion than sodium, in most of the fluids of the body. A small quantity of *Magnesium*, in the condition of Phosphate of Magnesia, is generally associated with calcium in the situations in which the last-named base is most abundant. The Red corpuscles of the Blood also contain an appreciable proportion of *Iron*, the presence of which seems essential to their production and functional power; but it scarcely shows itself by more than a trace in the solids and fluids generally.—Besides the foregoing, there are other elements which occur in such small and inconstant proportions, that their presence may probably be considered as accidental rather than as essential: such as iodine, fluorine, copper, manganese, and several other metallic bases.

2. *Inorganic Compounds.*

165. The foregoing elements are united in the Animal body into composite substances of various kinds; and of these we shall first notice those Inorganic Compounds which can be easily shown to exist *as such* in the living Organism, since they can be obtained from it by appropriate means without any operations which alter what is left behind. Of these, the most important place, in respect to amount and to importance, is held by *Water;* which is estimated to constitute between two-thirds and three-fourths, by weight, of the Human body, and the presence of which is essential to all the changes which are continually taking place in its substance. Water serves as the medium by which all alimentary material is introduced into the system; for, until dissolved in the juices of the stomach, food cannot be truly received into the economy. I

is water which holds the organizable materials of the blood either in solution or suspension; and thus serves to convey them through the minutest capillary pores into the substance of the solid tissues. It is water, which, mingled in various proportions with the solid components of the various textures, gives to them the consistence they respectively require. And it is water that takes up the products of their decay, and conveys them, by a most complicated and elaborate system of sewage, altogether out of the system.—The following are the per-centage proportions in which Water is contained in some of the principal tissues and fluids of the Human body:—

Epidermis	3·7	Bile	88·0
Teeth	10·0	Milk	88·7
Bones	13·0	Pancreatic Juice	90·0
Cartilage	55·0	Urine	93·6
Muscles	75·0	Lymph	96·0
Ligaments	76·8	Gastric juice	97·5
Brain	78·9	Perspiration	98·6
Blood	79·5	Saliva	99·5

Thus we see that it is only in the dermal and internal skeletons, whose function is purely mechanical, and the type of whose perfection is *hardness*, that the proportion of water is below one-seventh; in the Muscular substance, which forms a large proportion of the bulk of the body, it is as high as three-quarters; whilst in the Nervous tissue there is nearly as much water as there is in the Blood, of which fluid water constitutes about four-fifths. Water is being continually introduced into the system, not merely in its liquid form as drink, but also, in greater or less proportion, in every article of what we are accustomed to call solid food: and it is as constantly passing off by the several channels of excretion, in a liquid form by the kidneys and the intestinal canal, and in the state of vapour by the cutaneous and pulmonary exhalation. The average quantity of water daily taken-in by a healthy adult Man, has been estimated at about $4\frac{1}{2}$ lbs.; and a like amount is daily discharged from the body, with an addition which has been generated in the economy itself (§ 197), The entire elimination of water is pretty equally divided between the liquid and the gaseous, the latter being usually somewhat in excess; but the relative proportions of liquid passing off by the Kidneys, and of vapour exhaled by the Skin, are liable to be greatly affected by the temperature and the hygrometric state of the atmosphere (§ 745).

166. The fluids of the body and the watery portion of the solids almost universally (the Enamel of Teeth being the only known exception) hold in solution *Chloride of Sodium* or common Salt; the presence of which seems to be essential to the maintenance of their normal constitution. The following are the per-centage proportions in which it occurs in some of the principal solids and fluids of the body:—

Muscles	·2	Bile	·35
Bones	·25	Blood	·45
Milk	·1	Mucus	·6
Saliva	·15	Aqueous humor	·11
Urine	·3	Vitreous humor	·14

In the Blood, its amount rather exceeds that of all the other saline ingredients put together; but in the Muscles it is less abundant than chloride of potassium. The proportion of salt in most articles of food, whether animal or vegetable, is smaller than that which is proper to the animal body as a whole; and as there is a continual elimination of this substance in the urine, there is necessarily a demand for some special supply of it as a part of the ordinary diet; and Man and Animals alike show a special craving for it, when it is withheld from them during any length of time. Thus in most parts of the world inhabited by herds of wild cattle, there are natural sources of salt (such as the 'buffalo-licks' of America) to which they resort for the purpose of obtaining it; and it has been found by experiments upon domesticated cattle, that a regular supply of salt is essential to their continued well-being, although it may be withheld for a time without any marked effect. One specially important purpose answered by the presence of chloride of sodium in the animal economy, is its supply, by the separation of its components, of the chlorine, which, in union with hydrogen, forms the hydrochloric acid that is an essential ingredient of the gastric juice; and of the sodium, which, in union with oxygen, forms the soda that is an important constituent in the bile. The acid and the base come together again, however, in the alimentary canal; and chloride of sodium is thus reconstituted.—Although *Chloride of Potassium* is not nearly as universally present in the body as the soda-salt, yet its predominance in the muscles and in the red corpuscles of the blood shows that it has some special office in the economy; and, like common salt, it is continually being introduced in the food, whilst it as constantly passes off by the urine.—The *Carbonates of Soda and Potass* are very constant and important constituents of the body; soda (as in the preceding instance) being predominant over potass as the base. These carbonates answer the very important purpose of giving to the blood the slight alkalinity which is requisite for the maintenance of the solubility of albumen, as well as for various chemical processes subservient to the well-being of the economy. Of these carbonates, a part is introduced as such in the food; but the greater proportion, where fruits and succulent vegetables enter largely into the diet, is derived from the decomposition of the malates, tartrates, and citrates of soda and potass which they contain. In purely herbivorous animals, the urine is rendered alkaline by the presence of these carbonates; but in carnivorous animals, and ordinarily in Man, their quantity is not sufficient to saturate

the uric acid which is one of the products of the retrograde metamorphosis of the albuminous compounds taken-in as food, with the sulphuric and phosphoric acids which are generated in the body by the oxidation of the sulphuric and phosphorus united with these compounds; and the urine is consequently acid, save when an unusual proportion of the alkaline citrates, &c., has been ingested.

167. Of the Earthy salts contained in the body, *Phosphate of Lime* is by far the most important and generally diffused; for whilst it is the chief solidifying ingredient of the bony skeleton of Man and the higher Animals, it is met-with in small quantity in every one of the softer tissues, and also in every fluid. The following is its per-centage proportion in some of the principal components of the fabric:—

Enamel of Teeth . .	88·5	Muscles.	·25
Dentine	64·3	Blood	·03
Bones	55·0	Gastric juice. . . .	·04
Cartilages	4·0		

The Phosphate of Lime, which gives solidity to the skeleton, seems to be intimately united with its gelatinous matrix, and not to be deposited mechanically by an interposition of detached particles, as when flints are mixed up with mortar in a wall; and a like union appears to exist between this salt and albuminous matter in the blood, by which union phosphate of lime is held in a state of perfect solution in the circulating fluid, although it is insoluble both in water and in alkaline liquids. This substance is contained abundantly in many articles of vegetable diet, especially the corn grains and potatoes, as well as in the flesh of animals; it is peculiarly abundant in Milk, in which it is held in solution by casein. Of that which is introduced into the body as food, the superfluous portion appears to be voided by the fæces, without being absorbed into the current of the circulation. The process of nutrition, which involves a continual demand for new material, also sets-free an equivalent amount of the old; and although the bony skeleton of the adult might seem to be so permanent in its constitution as not to be the subject of any such interchange, yet there is evidence that nutritive changes are continually taking place even in the Osseous substance. Thus there is always a demand for the removal of the phosphate of lime which has served its purpose in the economy; and this is mainly carried out by the urine, in which it is held in solution by the acid phosphate of soda.—*Carbonate of Lime* is an important component of the Bones and Teeth of Vertebrata, usually constituting about one-sixth or one-seventh of the whole amount of bone-earth; the 'otoliths' or concretionary particles found in the internal ear are almost entirely composed of it; and it is the hardening material of the shell of the Bird's egg. It is, moreover, the chief solidifying material

of the skeletons of the Invertebrata; the shells of Mollusks and Echinoderms, and the calcified axes of the Stony Corals, being almost entirely composed of it. Though it does not seem to be an ordinary component of the softer tissues and fluids in Man, yet it sometimes occurs in his urine; and it is very constantly present in that of the Horse, in which it forms minute pearly concretions. In either case it must, of course, have pre-existed in the blood.—*Phosphate of Magnesia* commonly accompanies Phosphate of Lime in the solids and fluids of the body; but its proportion is comparatively minute. It seems to be introduced, like bone-earth, in the food, and to pass through the system unchanged; being held in solution in the blood by the alkaline chlorides and phosphates, and in the urine by the acid phosphate of soda.

168. In addition to the foregoing, any soluble salt which does not act immediately as a poison, may for a time be a constituent of the animal body; for every such salt taken into the alimentary canal is readily introduced by absorption into the current of the circulation, usually to find its way out again speedily by the urine,—the Kidneys serving as emunctories for the removal alike of saline substances which are foreign to the composition of the organism, and of those which, though proper to it, are present in excessive amount. There are certain metallic substances, however, which seem to form definite compounds with the organic components of the tissues, being withdrawn from the circulating current, and fixed in particular localities, so that they remain as permanent constituents of the organism, though not properly belonging to it; such are the salts of Lead, which are specially deposited in the muscles, those of Copper, which unite with the substance of the liver, and those of Arsenic and Antimony, which seem to have a special affinity for the mucous membranes. These substances, consequently, act as *cumulative* poisons; for whilst the action of such as are speedily eliminated is transient, and very commonly ceases with their removal, the worst effects of such as accumulate in the organism are only manifested after a long period,—as we see in lead-poisoning, and in chronic poisoning by arsenic and antimony.

3. *Organic Compounds.*

169. We have next to speak of those Organic Compounds which form the essential components of the Animal body; and with these it will be convenient to notice the chief substances which are supplied to its use by the Vegetable kingdom, but which are turned by it to some other purpose than that of serving as materials of its own fabric. It has been already pointed out as a distinctive attribute of the Animal Organism, that it is mainly dependent for the materials of its development upon substances which have

been previously elaborated by the agency of Plants (§ 15); these substances being either *ternary* compounds of Carbon, Oxygen, and Hydrogen, or *quaternary* compounds of the foregoing elements with the addition of Nitrogen. And if we throw together the 'proximate principles' which the Plant supplies to the Animal, and those of which the Animal body is itself composed, we shall find that those of *ternary* composition may be ranged under *three* principal groups, the *Amylaceous*, the *Saccharine*, and the *Oleaginous*, all of them closely related to each other; whilst the *quaternary* compounds for the most part belong to two groups, the *Albuminous* and the *Gelatinous*. Each of these groups will now be noticed in detail; and some account will also be given of certain other substances which appear to be formed in the course of the *retrograde* metamorphosis, whereby the Albuminous and Gelatinous compounds are ultimately resolved into the inorganic binary compounds (§ 15) that afford the essential *pabulum* of Vegetable growth. Such substances can scarcely be regarded as true components of the Animal organism; since they are formed in it only as products of decay, for the speedy removal of which a very elaborate provision is made.

170. *Amylaceous Compounds.*—The ultimate composition of all the Amylaceous or Starchy substances is the same, viz. C^{12}, H^{10}, O^{10}, *twelve* proportionals of Carbon being united with *ten* proportionals of the components of Water. There are, however, important differences in their state of molecular aggregation, which affect their behaviour when treated with re-agents. The vegetable *protoplasm* or organizable fluid,—generated by the Plant at the expense of the Water, Carbonic acid, and Ammonia of the atmosphere,—constantly holds amylaceous matter in solution, as is shown by the characteristic blue which it gives with iodine; and of this matter one part is generally exuded in the condition of Cellulose, to form a protective envelope to that delicate pellicle which essentially constitutes the wall of the Vegetable cell (§ 22); whilst another portion, stored-up in the cavity of the cell under the form of minute granules having a peculiar effect upon polarized light, is known as Starch. *Cellulose* is a colourless, tasteless, odourless, semi-transparent solid, insoluble in cold water, alcohol, ether, or the fixed or essential oils; it may be converted by the prolonged action of boiling water into dextrin; and the same conversion is effected by the action of concentrated sulphuric or phosphoric acid. Cellulose is readily distinguishable from Starch by not giving a blue tint with iodine until it has been acted-on with sulphuric acid. It may be doubted whether Cellulose already deposited in the fabric of Plants can be appropriated as food by Animals; for it would not seem to be soluble in the juices of the stomach; and the cellulose-walls of the Vegetable tissues are distinctly recognizable in the fæces. There is no doubt,

however, that Cellulose is a normal constituent of the organism of some of the lower animals; having been found to be constantly present in the 'test' or outer leathery envelope of the Tunicated Mollusks. And it seems also to present itself occasionally in various parts of the Human body (chiefly in the substance of the brain and spinal cord); though its appearance there may not improbably depend upon an interruption of the ordinary metamorphosis of the Hepatine that is continually being formed in the liver (§ 172). It is in the form of *Starch* that the Amylaceous principle is most largely supplied by Plants for the nutriment of Animals. Nearly all Vegetable substances used as food contain it abundantly; and such preparations as Sago, Tapioca, Arrowroot, etc., consist of little else. When purified from foreign substances, Starch presents itself in the condition of a soft, white, and often glistening powder; the granules of which, when examined with the microscope, are found to have a more or less rounded form (Fig. 2), and to be marked by a series of concentric circles which surround a spot termed the *hilum*. The size and shape of these granules vary with their source; the starch-grains of the Potatoe, of Arrowroot, and of 'Tous les mois,' being much larger than those of the Corn-grains, which last are usually flattened, and not distinctly marked by concentric circles. Starch is insoluble in cold water, in alcohol, and in all other liquids which do not effect its decomposition; but when boiled in water (as in the ordinary preparation of Arrowroot) its granules first swell, then become gelatinous and opaline, then fuse with each other, and finally liquefy altogether, provided a sufficient quantity of water be present, forming a gelatinous liquid which thickens on cooling. This, when dried, becomes a yellowish horny substance resembling gum, which, when put into cold water again, softens and swells but does not dissolve. Notwithstanding its complete change of physical condition, the 'amorphous' or 'gelatinous' starch thus produced does not seem to differ chemically from ordinary starch; its ultimate composition being unchanged, and its characteristic reaction with iodine being the same.

Fig. 2.

171. When 'gelatinous' starch is boiled with a small quantity of dilute sulphuric, hydrochloric, or almost any other acid, it speedily loses its gelatinous consistence, and becomes thin and limpid; having suffered conversion into a gum-like substance,

oluble in cold water, which is termed *Dextrin*. This substance, which may also be obtained from ordinary Starch by the action of eat alone, and from Cellulose by the action of strong sulphuric cid, still retains the ultimate composition of starch, but differs rom it widely in certain physical and chemical re-actions. It is istinguished by its peculiar action on polarized light, causing the lane of polarization to rotate towards the right hand; and by his property (from which its name is derived) its presence may be ecognized in the vegetable juices. On the other hand, it has lost ltogether the power of striking a blue colour with iodine. Dextrin is a substance of peculiar physiological interest, from its xhibiting an intermediate stage in that conversion of Starch into ugar, which is continually taking place in the economy both of 'lants and Animals. This conversion may be effected by the ontinued action of sulphuric acid and heat upon dextrin; but it s much more rapidly accomplished by the agency of certain lbuminous substances in a state of change, which act as *ferments*. 'hus in germinating seeds, and in buds in a state of development, he starch previously stored-up in the tissues is converted into ugar by the production of a substance called *Diastase*, which xerts the same power when separated from the plant. Thus, if ve mix a small quantity of an infusion of malt in tepid water vith a large mass of thick gelatinous starch, and subject this to a emperature of about 160°, a complete liquefaction of the starch nto dextrin occurs in a few minutes, and this in its turn becomes onverted in the course of a few hours into grape-sugar. A still nore powerful ferment of the same kind exists in the Saliva of Ian; for if this fluid be mixed with boiled starch, an interval of nly a few minutes at the temperature of the living body is sufficient for the production of sugar. It is by means of this change hat starch is made available by Animals. We shall see that the Digestion of amylaceous substances really consists, not in their nere solution, but in their saccharine conversion; and if starch be ntroduced into the alimentary canal in such amount that it cannot e all turned into sugar, it passes off unchanged in the fæces.

172. The very important fact has been recently discovered, hat an Amylaceous substance is continually being produced in arge amount in the Animal economy, by the retrograde metamorphosis of Albuminous compounds, which seem to resolve themselves into simpler forms in preparation for ultimate decomposition. This substance, known as *Hepatine* or *Glycogen*, is specially produced in the Liver; from which organ it may be obtained by ppropriate means. When properly prepared, Hepatine presents tself under the form of a white powder, which resembles amorphous Starch in composition and properties; being tolerably oluble in water, which it renders opaline; giving a violet hue vith iodine; and readily undergoing conversion by ferments, first

into dextrin, and then into sugar. Such a ferment seems normal to exist in the Liver; but its power, like that of diastase, destroyed by boiling, which probably occasions its coagulatio and it may also be neutralized (as Dr. Pavy has shown) by injec ing the liver with a strong solution of citric or tartaric acid.] either of these modes, the conversion of hepatin into sugar, whi continues to go on after death even when the blood has be completely washed out of the vessels of the liver by the injecti of copious streams of pure water, may be completely checked; that it may be demonstrated, that the substance generated l the Liver is not Sugar (as was first supposed by Bernard), bi is one that is changed into sugar with extreme facility. Th the secretion of this substance does not depend upon the presen of Amylaceous matters in the food, but may take place at tl expense of Albuminous compounds, appears to have been satisfa torily proved by a variety of experiments; which have show that the production of sugar continued alike in the livers of an mals that had been fed upon an exclusively azotized diet, and i those also from which food had been so long withheld as to mal it certain that any amylaceous matters ingested must have bee previously used-up; whilst, on the other hand, this production di not appear to be augmented by the presence of amylaceous sul stances in the food, these appearing rather to be converted int fat. The conversion of hepatine into sugar seems to be promote by the presence of a 'ferment' not merely in the liver itself, bi also in the blood circulating through it; and the circulating cu rent carries off the sugar as fast as it is formed, to dispose of ultimately in the manner to be presently described (§ 174).

173. *Saccharine Compounds.*— Under the general designatic *Sugar* are ranged a considerable number of substances which a intimately related to each other in composition and in their mo important properties, and are to a certain extent mutually co vertible. They are all readily soluble in water, and crystalli more or less perfectly in evaporation; they have a distinct swe taste; and they may be all resolved by fermentation, eith directly, or by passing through the intermediate condition (Glucose, into Alcohol and Carbonic Acid. Of these varieti those only will be here noticed which have the greatest interest t the Physiologist.—The crystalline aggregation, sweet taste, an solubility in water are most distinctly possessed by *Cane-Suga* so called from its being most largely drawn from the sugar-cane the same kind of sugar, however, is found in the juice of many c the Grasses, in the sap of the Maple (from which sugar is largel derived in North America), in the root of the Beet (which fur nishes a considerable part of the sugar used on the Continent), an in several other plants. Pure cane-sugar separates from a stron solution in large, transparent, colourless crystals, which have th

gure of a modified oblique rhombic prism. It is very soluble in ater, requiring for its solution only one-third of its weight in e cold; and it is also dissolved by alcohol, though with more fficulty. Its ultimate composition is represented by the forula C^{12}, H^{11}, O^{11}, which is the same as that of Starch with the ldition of one equivalent of Water; but from the study of the mbining proportion of sugar with other substances, it is conuded by M. Peligot that the numbers of the component elements iould be doubled to represent crystallized cane-sugar, and that iis substance really consists of a compound of C^{24}, H^{18}, O^{18}, with equivalents of Water, for which protoxide of lead may be subituted. Cane-sugar is much less liable to change than most her saccharine compounds; it does not give any reaction with rommer's test, nor does it undergo either the alcoholic or the ctic acid fermentation, until it has been converted into Glucose; ut this conversion is readily effected by chemical means, and it ikes place so speedily under the influence of organic 'ferments' onstantly present in the living body, that within a very short me of its introduction, even in large quantities, it altogether isappears. Consequently it is chiefly interesting to the Animal hysiologist as one of the sources of the supply of Glucose.

174. *Glucose* or Grape-Sugar, also, is abundantly diffused irough the Vegetable Kingdom; being yielded in greatest mount by ripe fruits, but being also exuded in the honey of owers. It is much less sweet than cane-sugar; and is less oluble in water, requiring $1\frac{1}{2}$ parts of cold water for its solution. t is also soluble in proof-spirit; but to a less extent than caneugar in absolute alcohol. Its mode of crystallizing also is comletely different; for instead of forming bold distinct crystals, t separates from its solutions in water and alcohol in granular rarty masses, which but seldom present crystalline faces. The ultimate composition of Grape-sugar may be represented y the formula C^{12}, O^{12}, H^{12}; but, as in the preceding case, it eems probable that its real combining equivalent is C^{24}, H^{21}, O^{21}, this being united in crystallized grape-sugar with 3 HO. The presence of Glucose may be most readily detected in minute uantity by means of what is known as Trommer's test; he action of which depends upon the property possessed by Glucose of reducing the per-salts of Copper when heated with hem in an alkaline solution. In using this test, the suspected iquid should first be rendered alkaline by the addition of caustic otassa, and a solution of sulphate of copper should then be ery cautiously added, until a blue tinge is given; on boiling he mixture, if Glucose be present, the insoluble suboxide of copper is thrown down as an opaque red, yellow, or orangeoloured deposit. The reduction of the sugar may be prevented, iowever, by the presence of albuminous substances; and the test

can only be satisfactorily used, therefore, after appropriate means have been taken for their removal. As already stated, the copper test gives no reaction with Cane-sugar; but if that substance be boiled for a few minutes with a trace of sulphuric acid, it becomes converted into Glucose, and the characteristic result is then exhibited. Glucose is a much more unstable substance than Cane-sugar; being very readily acted-on by 'ferments,' under the influence of which its components undergo an entire re-arrangement. In the Alcoholic fermentation,—which may be brought about not only by the agency of Yeast, but by the presence of azotized matters in a state of decomposition approaching putrescence,—the elements C^{12}, H^{12}, O^{12}, resolve themselves into 2 equiv. of Alcohol (C^4, H^6, O^2) + 4 equiv. of Carbonic Acid (CO^2). This transformation (which enables the quantity of sugar in diabetic urine to be determined by the amount of carbonic acid given off when yeast is mixed with it) does not seem to take place normally in the living body; the ferments there encountered by the glucose, which seem to be produced by an earlier stage of decomposition of albuminous compounds, occasioning its resolution into *Lactic acid*, the combining equivalent of which is C^6, H^5, O^5, with one equiv. of basic HO; so that two equivalents of this compound exactly represent the composition of Glucose. By a further metamorphosis, which seems to take-place under the influence of the ferments of the blood with the addition of the oxygen of the inspired air, lactic acid is resolved into Carbonic acid and Water; and the exhalation of these substances from the lungs seems to be the ordinary mode by which the elements of the Saccharine compounds introduced into the body or generated in its interior are eliminated from it.—Glucose, as already seen, is not only supplied as such by certain articles of Vegetable food, but is also readily produced at the expense of other components of the food, Starch, Dextrine, and Cane-sugar; the transformation of the first and second taking place in the Alimentary canal, and that of the third in the passage of the Portal blood, which has taken it up in the Mesenteric vessels, through the substance of the Liver. But it is also largely produced by the transformation of the Hepatine which we have seen to be generated in the Liver; so that the blood of the Hepatic vein and Vena Cava is charged with sugar, even when none existed in the Portal blood. Unless this sugar be present in an unusual proportion, however, or the respiratory process be impeded, it is not traceable further than the Lungs; the sugar conveyed to them in the blood of the Pulmonary Artery being entirely eliminated in the form of Carbonic Acid and Water (probably passing through the intermediate stage of Lactic acid), so that the Arterial blood returning by the Pulmonary vein is entirely free from it. But if there be either an excessive production of Sugar (as in Diabetes) or an impediment to its elimin-

ion (as in cases in which the respiratory process is inadequately rformed) the Sugar passes into the Arterial circulation, and then nds its way into the urine. Whether all the Sugar introduced to the body or generated in its interior is thus disposed of, can-ot at present be stated with certainty; many circumstances vour the belief that a portion of it may be converted into Fat.

175. Another Saccharine substance of considerable Physiological terest is *Lactose* or Sugar of Milk, an important constituent of iat secretion. This substance, obtained by the evaporation of hey, crystallizes in white, translucent four-sided prisms of great ardness. It is dissolved slowly and with difficulty in cold water, which it requires 5 or 6 times its own weight; it is entirely soluble in absolute alcohol. It agrees with Glucose in composi-on, and also in its reaction with Trommer's test; but it differs om it not only in the foregoing characters, but also in not under-oing the alcoholic fermentation until it has been converted into lucose; which conversion may be effected, like that of Cane-igar, by boiling it with dilute mineral acids. Under the in-uence of the casein of milk, it is very readily converted into actic acid. There can be no doubt that the proportion of actose in milk is partly dependent upon that of Saccharine or mylaceous substances in the food; but it appears certain also iat Lactose is present also, though in comparatively small quan-ty, in the milk of Carnivorous animals restricted to a flesh-diet; nd hence it is to be inferred, that it may be produced, like lycogen, at the expense of Albuminous substances. We seem have another instance of the like production in the general resence of *Inosite*, or Muscle-sugar, in the tissues of Animals. his form of sugar was originally found in the juice of the mus-ular tissue of the heart; but it has been since detected in that of ther muscles, and also in the substance of the lungs, liver, pleen, and kidneys. It crystallizes with 4 equiv. of Water in olourless, four-sided prisms, has a sweet taste, dissolves readily a water and slightly in strong spirit, and is insoluble in absolute lcohol. It does not reduce oxide of copper, nor does it undergo lcoholic fermentation, but it is readily transformed into lactic cid when in contact with casein or other albuminous compounds; nd as lactic acid may be extracted abundantly from muscles that ave been much exercised, it is probable that the formation of nosite is the intermediate stage of its production in the retro-rade metamorphosis of the Albuminous components of the nuscle. The most distinctive property of this substance is the eautiful rose-tint which it gives when evaporated with nitric cid nearly to dryness, then mixed with a little ammonia and hloride of calcium, and again evaporated to dryness. It seems in s anhydrous state to be identical in composition with anhydrous lucose; but as it is with difficulty obtainable in any considerable

quantity, its characters have not yet been fully determined. Many other varieties of Sugar have been enumerated; but their apparent differences seem often to depend upon the admixture of minute quantities of other substances, from which it is by no means easy to free them. Thus Diabetic Sugar was at one time regarded as different from Glucose; although the identity of the two has now been made certain.

176. *Oleaginous Compounds.*—Every Animal body contains a certain amount of Oily or Fatty matters, intimately blended with Albuminous compounds in the protoplasmic substance which constitutes the formative material of its tissues (§ 178); and there is besides, in the bodies of the higher animals, a special tissue—the Adipose—which constitutes a storehouse of these matters, to be drawn upon when the supply afforded by the food is deficient. Fixed Oils are largely generated in the Vegetable kingdom, and abound in various substances commonly used as food by Animals, especially certain seeds and fruits; and there can be no doubt that the greater part of the materials of Animal Fat are thus derived from Plants, in forms either identical with those generated by Vegetable life, or but slightly modified from these. But it is also certain that Animals have the power of generating Fat for themselves; and it appears that this may be produced either by a metamorphosis of Saccharine compounds, or by a breaking-up of the Albuminous. The peculiarity by which all the Oleaginous Compounds are essentially distinguished, is the predominance of Hydrogen and Carbon in their composition; the proportion of Oxygen they contain being extremely small, instead of being (as in the Amylaceous and Saccharine Compounds) the equivalent of the Hydrogen. There are three which particularly require notice as occurring largely in the Animal kingdom, viz., *Stearin*, *Margarin*, and *Olein;* the two former, when isolated, are solid at ordinary temperatures, whilst the latter is not only liquid at ordinary temperatures, but remains so at the zero of Fahrenheit. The consistence of the different varieties of fat, oil, &c., depends upon the proportions in which these components are united; neither of them existing separately, but Stearin or Margarin or both together being held in solution by Olein. Thus ordinary Olive oil consists of a solution of Margarin in Olein, which remains liquid until it is cooled down to 40°; below that point, however, the Margarin congeals into a crystalline solid fat of a pearly aspect, the melting point of which is 12°. This substance is the principal solid constituent of Human fat, and it occurs in smaller proportion in other Animal fats. The chief solidifying ingredient of the latter, however, is usually Stearin; which is most abundant in the hardest fatty substances, such as mutton-suet, which, although liquid at the temperature of the living body, becomes solid when it cools to the ordinary temperature of the atmosphere,

and the Stearin then commonly separates itself from its solution in a crystalline form, the crystals presenting the aspect of slender needles which are sometimes straight but more often curved, and are generally deposited in a more or less radiating manner, so as often to present very elegant, branched, or arborescent arrangements. When thus isolated, it has the aspect of spermaceti, is not at all greasy between the fingers, and melts at about 130°. Margarin is entirely insoluble in water, and nearly so in cold alcohol; but it is readily soluble in boiling alcohol, and in ether either hot or cold. Stearin is much less soluble in boiling alcohol, and is scarcely at all soluble in cold ether. Olein can scarcely be obtained pure, owing to the difficulty of separating the last portions of the Margarin always united with it in natural fats and oils. It is a limpid fluid which quickly becomes rancid by exposure to air, in consequence of the production of butyric and other fatty acids by its oxidation; and it is miscible with alcohol in all proportions. The formulæ of these substances now generally accepted are:

Stearin	C^{114}, H^{110}, O^{12}
Margarin	C^{108}, H^{104}, O^{12}
Olein	C^{114}, H^{104}, O^{12}

177. When any kind of fat or oil is boiled with a solution of caustic alkali in water, it undergoes the change which is termed *saponification;* a homogeneous, viscid, transparent *soap* being formed, which is freely soluble in warm water, though insoluble in saline solutions; whilst a peculiar sweet, viscid, heavy liquid termed *glycerin* is set free, composed of $C^6\ H^8\ O^6$, mixing with water in all proportions, and having, like it, a remarkable power of dissolving other substances. If the alkali be withdrawn from the soap by the addition of an acid, the fatty substance which is left is found to possess a strongly acid reaction, so as to be capable of forming salts with bases. Stearin thus treated yields *stearic acid;* margarin, *margaric* acid; olein, *oleic* acid; and common annimal fat, which is a mixture of the three neutral bodies, affords, when thus treated, a mixture of these three fatty acids. From this it would seem that a neutral fat is a compound of a fatty acid with glycerin as a base; and that the process of saponification consists simply in the displacement of glycerin by an alkaline base. But this would not be a correct account of it; for it is certain that water disappears in the process, being taken up by the components of the fat, so that the weight of the fatty acid and the glycerin base together exceed that of the neutral fat. Moreover, it is found that the fatty acid and glycerin may be generated from the neutral fat by the prolonged action of superheated steam alone,—a process largely used in the arts. And conversely, as Berthelot has shown, the prolonged action of the fatty acids upon glycerin in closed vessels at high temperatures, reproduces the

original neutral fats, *plus* certain equivalents of water. Recent investigations on the chemical relations of glycerin have shewn, that it is to be regarded as a triatomic alcohol, and that its real formula is $C^6 H^5 O^3 + 3 HO$, the three equivalents of water replacing three equivalents of the fatty acid. So, again, the true composition of the fatty acids appears to be as follows:—

Stearic Acid	$C^{36} H^{35} O^3 + HO$
Margaric Acid	$C^{34} H^{33} O^3 + HO$
Oleic Acid	$C^{36} H^{33} O^3 + HO$

each equivalent of acid being united with an equivalent of basic water, which replaces the glycerin. Consequently, the real composition of the neutral fats may be thus represented:—

Stearin . .	$C^{114} H^{110} O^{12} = C^6 H^5 O^3 + 3 (C^{36} H^{35} O^3)$
Margarin . .	$C^{108} H^{104} O^{12} = C^6 H^5 O^3 + 3 (C^{34} H^{33} O^3)$
Olein . .	$C^{114} H^{104} O^{12} = C^6 H^5 O^3 + 3 (C^{36} H^{33} O^3)$

When the acids are separated from their glycerin base, 4 equivalents of water disappear; 1 equiv. uniting itself with the acid, in substitution for the base, whilst 3 equiv. unite with the glycerin, in substitution for the like number of equiv. of the acid. And when the neutral fat is reproduced by synthesis, these 4 equivalents of water reappear.

178. The Fatty substances introduced as components of the food are subjected in the Alimentary canal to an *emulsifying* process, by which they are reduced to a state of extremely fine division; and their particles, diffused through an albuminous solution to which their presence gives a milky opacity, are absorbed into the Lacteals, constituting the peculiar fluid known as *Chyle.* This seems to be the crude or early condition of what is destined to become the 'protoplasma' or formative material, at the expense of which the tissues are generated; every 'plastic exudation' thrown out for the reparation of injuries, having minute granules of fatty matter diffused through it, like the 'sarcode' of the Protozoa. But there is no doubt, that, of the Fat introduced into the current of the circulation, a large part is turned at once to account as a generator of heat, by a process resembling combustion, without ever forming tissue; and it would seem to be specially as a reserve of combustive material, that another portion is withdrawn from the blood and stored up in the Adipose tissue, whence it may be received back again into the circulating current as occasion may require. Their condition in this tissue is altogether exceptional: for whilst the rest of the 'proximate principles' of which the animal organism is composed are associated with each other or with mineral substances, so as only to be separable by chemical analysis, oleaginous substances are deposited as such in the cavities of cells, from which they can be removed by pressure merely. And when taken up from these in the

ving body (as during emaciation), the tissue itself is not altered, ıt as each cell is gradually emptied of its oily contents, these e replaced by a serous liquid. The deposit of Fat in the body, owever, may take place not merely at the expense of oleaginous atters which have been introduced as such in the food, or have en generated by the metamorphosis of saccharine compounds; r there is ample evidence, that, like starch and sugar, fat may be nerated in the animal body by the 'retrograde metamorphosis' albuminous substances; its production being one of the means which the hydro-carbonaceous portion of those substances is iminated from the system through the respiratory process, whilst e azotized portion is got rid of through the kidneys. Of this e have evidence in the process of 'fatty degeneration,' which n be shown in many instances (as in the reduction of the uterus the unimpregnated state after parturition) to consist in an tual resolution of the tissue into fat, and not to be a substitution one substance for the other. And a like process sometimes curs after death, under the influence of the prolonged action of ater; the muscles and soft tissues generally being converted into spermaceti-like substance termed Adipocire.

179. *Albuminous Compounds.*—We have now to describe the *otized* substances which constitute, when mingled with a minute oportion of Fat, the *histogenetic* or tissue-forming material, ike of the Vegetable and of the Animal fabric. Their impornce in the Vegetable economy is masked, it is true, by the cess of non-azotized components in the tissues of the plant; but is now quite certain that these do not constitute the proper ving substance, but that they are excreted (so to speak) from is, to give firmness and tenacity to the texture. But besides hat is generated in the Plant for its own use, we find that in rtain situations large stores of a substance having essentially e same composition as Animal Albumen, are laid up in the ssues, especially of seeds,—as in the Corn-grains, Peas, Beans, c.; and from these sources Man is readily able to derive an nount adequate to his sustenance, when entirely cut off from the ıpply of Animal food. That Albumen and Fat, with the inorınic substances blended with them, may be converted into every rm of Animal tissue, is satisfactorily proved by the history of velopment in Birds and other Ovipara. For the *white* of the g consists of nothing else than Albumen combined with phosıate of lime; whilst the *yolk* is chiefly composed of the same subance, mingled with Oily matter and with a minute quantity of lphur, iron, and some other inorganic bodies. Yet these mateıls are converted, after the lapse of a few days, under the agency an elevated temperature upon the germ, into a complex fabric, mposed of bones, muscles, nerves, tendons, ligaments, cartilages, brous membranes, fat, connective tissue, &c., and endowed with

the properties characteristic of all these substances, which, when brought into consentaneous activity, manifest themselves in the life of the Chick.

180. The following is the composition of Albumen, according to the most recent analyses of two eminent chemists:—

	Scherer	*Mulder.*
Carbon	54·9	53·5
Hydrogen	7·0	7·0
Nitrogen	15·7	15·5
Oxygen		22·0
Sulphur	22·4	1·6
Phosphorus		0·4
	100·0	100·0

It seems probable, that Phosphorus is not (like Sulphur) a true constituent of Albumen, or of any of the Albuminous compounds; as it may be entirely separated from them without the destruction of their integrity. Albumen seems never to occur in the animal body, except in such intimate union with fatty and mineral substances, that it is with difficulty separated from them. The quantity of these is variable; but altogether they usually amount to at least 6 per cent., of which from 1 to 2·5 per cent. consists of phosphate of lime. But although the per-centage composition of Carbon, Hydrogen, Nitrogen, and Oxygen in Albumen has been determined with great care, chemists are not agreed upon the formula which should represent its combining equivalent; one difficulty in determining this arising from the presence of a minute proportion of Sulphur, which seems an essential constituent. If this be included in the formula, the very complex expression $C^{144} H^{112} N^{18} S^{2} O^{44}$ is required, according to Lieberkühn. A simpler formula, $C^{24} H^{17} N^{3} O^{8}$, has been proposed by Hunt, as sufficiently representing the per-centage composition if the Sulphur be omitted; and he has pointed out that this may be derived from the formula of Cellulose, by the addition of certain equiv. of Ammonia and the setting-free of certain equiv. of Water. Thus, $C^{24} H^{17} N^{3} O^{8} = 2 (C^{12} H^{10} O^{10} + 3 H^{3} N) - 12 H O$. That some such building-up of the complex atom of the Albuminous compounds from the simpler atom of the Amylaceous or Saccharine takes place in the Vegetable organism, cannot but be regarded as highly probable; and this probability is greatly strengthened by the study of the compounds which may be artificially produced, on the one hand synthetically by the action of ammonia upon sugars, on the other hand by the operation of reagents which break up Albumen into new combinations.

181. But besides the substance chemically distinguished as Albumen, the Animal body contains several other substances nearly related to it both in composition and general properties, which yet need to be separately distinguished on account of their

hysiological importance. All these *Albuminous Substances** occur ither in a *soluble* or in an *insoluble* or scarcely-soluble state ; their olubility appearing to depend, however, upon the presence of ther substances. The soluble modification, when dried, forms a aint yellow, translucent, friable mass, having no smell or peculiar aste ; it dissolves in water, but is insoluble in alcohol and ether ; ; is precipitated by alcohol from the aqueous solution, after which ; is usually insoluble in water. The aqueous solution is precipi- ated by most metallic salts, and the precipitate generally contains he acid and base of the salt employed, in addition to the albu- ainous substance. The greater number cannot be precipitated rom their aqueous solution by alkalies, or by most of the vegetable cids ; but they are precipitated by mineral acids (with the excep- ion of ordinary phosphoric acid) and by tannic acid ; and by some f these they are converted into their insoluble form. Into this, aoreover, the greater number of them are changed by boiling ; nd it is in this mode that their insoluble forms are commonly btained.—The insoluble compounds when dried are white and ulverizable, are destitute of taste or smell, have no action on egetable colours, and are insoluble in water, alcohol, ether, and ll indifferent menstrua ; but they are all more or less readily dis- olved by *alkalies*, from which they may be precipitated by mere eutralization with acids. In common with gelatigenous substances hey give with the acid nitrate of Mercury (Millon's test) a red olour, which becomes intense when the temperature of the liquid s raised to 212°, and does not disappear by prolonged boiling. All f them are acted-on in a peculiar manner by concentrated Nitric nd Hydrochloric *acids ;* the former giving them when heated a leep *lemon-coloured* tint ; whilst the latter causes them to assume gradually-increasing *violet* hue, which becomes intense when hey are exposed to warmth and air. They are all dissolved by oncentrated Acetic acid and other Organic acids, as well as by Phosphoric acid ; and are precipitated from these solutions by errocyanide of potassium. Their behaviour towards other acids, however, is not so uniform, and must be separately noticed in each ase.—All Albuminous substances contain Sulphur, which seems o be one of their essential constituents, not being capable of entire limination without the complete destruction of the organic sub- tance, although a part may be withdrawn by digestion with ixed alkalies.—Albuminous substances, again, are very liable to lecomposition ; this change taking place in them spontaneously

* These substances are not unfrequently termed 'protein-compounds'; it aving been affirmed by Mulder that they are formed by the union of sulphur nd phosphorus in different proportions with a common organic base, to which, as the foundation of the whole series of histogenetic compounds, the ame of *protein* was thought appropriate. Although it has been proved hat this idea is erroneous, yet the general term founded upon it is still requently employed.

when they are exposed to the air at ordinary temperatures, and being very readily induced by oxidizing agents, alkalies, &c., the effect of which is promoted by heat. From the recent experiments of Pasteur, however, it appears that this change will not take place unless the germs of some low forms of Animal or Vegetable life are present, the development of which is essential to the act of decomposition (§ 39 *note*). This change in their condition not merely involves the re-arrangement of their own elements in new compounds of a different character, but also tends to produce similar changes in other substances (§§ 466, 471); and it is probable that this kind of agency takes-place to a great extent in the living body. This property makes it very important that the history of the Albuminous substances in the living body should be fully made out; since it is obvious that they are not merely required as histogenetic materials, but that they also take an important part in the transformation of other substances by their action as *ferments.*

182. The properties of *Albumen* may be studied in the white of the egg, or in the serum of the blood, from either of which situations it may be obtained in a nearly pure state by very simple means. These two forms of it, however, are not precisely identical; indeed it appears from recent inquiries that striking differences are produced in albumen, not merely by the presence of some other body, such as an alkali or a salt, but by the different proportions in which this occurs; and hence various and contradictory statements have been made in reference to the properties of this substance. The following are the facts of most physiological interest:—In the before-mentioned animal fluids, as well as in several others, Albumen exists in its soluble form, but not in an isolated state; for it is united with soda as an acid to its base, and thus may be formed a basic, neutral, or acid albuminate of soda. The *basic* compound, which contains about $1\frac{1}{2}$ per cent. of soda, and gives a slightly alkaline reaction, is the one which ordinarily presents itself in normal blood, as well as in the egg; it is far more soluble in water than is pure albumen, which, indeed, when *entirely* separated from all other substances, is probably not soluble at all; and it differs from pure albumen, moreover, in the mode in which it coagulates on the application of heat, for whilst the latter separates in flakes, sodo-albumen forms a white gelatinous mass, or, if the fluid be much diluted, makes itself apparent only by a milky or opalescent turbidity. A moderately-strong solution of albumen in water becomes turbid at 140°, becomes completely insoluble at 145°, and separates in flakes at 167°: when excessively diluted, however, no turbidity can be produced by a less heat than 194°; and coagula will only separate after it has been boiled a considerable time. But after having been dried *in vacuo* or at a temperature below 120°, albumen may be heated to 212°

without passing into the insoluble condition.* Albumen may be precipitated from an aqueous solution by diluted alcohol; but it does not pass into the insoluble form, unless a large quantity of strong alcohol be added. It is also precipitated by creosote. Albumen is converted into the insoluble form by most acids; but it is not precipitated by the mineral acids, unless they are added in excess; and the organic acids, with the exception of the tannic, do not throw it down. It is converted into the insoluble form by alkalies, but is not precipitated by them, being held-up by their presence. The greater number of metallic salts precipitate albumen, which generally passes into the insoluble state, and enters into combination, either with the basic salt itself, or with its acid and its base separately; one of these salts, the albuminate of the chloride of mercury, is of much interest, as being that which is produced by the mixture of a solution of albumen with one of corrosive sublimate.—Albumen is found in all the *nutritive fluids* of the body, as the Blood, the Chyle, the Lymph, and the serous exudation which percolates through the interstices of the tissues. From several of the *tissues*, also, it may be obtained in considerable abundance; but it is not always easy to say whether it is a natural constituent of such tissues, or whether it is simply left by the fluid with which they were charged. It cannot be said that Albumen is a normal constituent of any of the *secreted* fluids, such as the salivary, gastric, or pancreatic; the peculiar organic constituents of these being apparently albuminous substances in a state of change. And among the proper *excretory* matters, it is certain that albumen is never found but in consequence of morbid action; its appearance indicating either disease of the excreting organ, or a marked alteration either in the composition of the blood or in the mode of its circulation.

183. Nearly allied to Albumen is the substance termed *Casein*, which replaces it in Milk; and this is specially worthy of notice here, because it is the sole form in which the young Mammal receives albuminoid nutriment into its body during the period of lactation. Like Albumen, this substance may exist in two forms, the soluble, and the insoluble or coagulated; and it further agrees with albumen in requiring as a condition of its solubility the presence of a free alkali, of which, however, a very small quantity suffices for the purpose. It differs from Albumen, however, in this; that it does *not* coagulate by heat, and that it *is* precipitated from its solution by Acetic and Lactic acids. Casein is further remarkable for the facility with which its coagulation is effected by the contact

* This fact is of much interest in relation to the experiments of Doyère and others upon the tenacity of life of the *Tardigrade* tribe allied to Rotifera (§ 159); for it has been found, that, *when completely desiccated*, the bodies of these animals might be exposed to a heat of 250°, without the destruction of their vitality.

of certain animal membranes, as in the ordinary process of cheese-making. It is uncertain whether there is any essential difference in composition between Casein and Albumen, or whether they are 'isomeric' compounds having the same elementary composition. In their coagulated state, they scarcely differ in properties. Casein appears to be readily converted into Albumen in the digestive process; being coagulated, when introduced in the liquid form, by the gastric fluid, and then dissolved by it. Casein appears even to surpass Albumen in its power of combining with the phosphates of lime and magnesia, and of rendering them soluble; as much as 6 per cent. of phosphate of lime being usually obtainable from it. A substance resembling casein is obtainable from the serum of the blood; being met-with in unusually large proportion in the blood of pregnant females, and especially in that of the placenta. Casein is also found in the serous liquid which is diffused through the tissues, especially that of the muscles and of areolar tissue. It is found also, mingled with albumen, in the yolk of the egg; this mixture has been known under the distinctive name of *vitellin.* All the liquids containing Casein are such as appear to have it for their special function to supply formative materials for rapidly-growing tissues; and we are, therefore, in all probability to regard this substance as still more closely related to them, than is albumen itself.

184. The substance of which Muscles are composed was long considered to be Fibrin; but it differs essentially from fibrin in its properties (being at least as much allied to albumen), and is now distinguished as *Syntonin.* Its special chemical peculiarity is its solubility in very dilute hydrochloric acid (1 part to 100 of water), and its precipitation in the form of a jelly when the acid is neutralized; this jelly forms, with lime-water or very dilute alkaline solutions, a solution which coagulates by heat; and thus it seems to be reduced nearly to the condition of Albumen. This is, in fact, very much what takes-place in the act of digestion of flesh-meat; the muscle-substance being first dissolved by the hydrochloric acid of the gastric fluid, and the solution being then rendered alkaline by the mixture of bile and other secretions in the small intestine.

185. The fluids that are formed at the expense of the Albuminous matters which have been digested and absorbed, contain a substance, *Fibrin*, which is so closely related to Albumen in its ultimate chemical composition as not to be distinguishable from it with absolute certainty, but which, though fluid whilst circulating in the living vessels, spontaneously coagulates when withdrawn from them, presenting a more or less definite fibroid texture. It is found in the Chyle or crude blood, soon after this is taken-up from the food; it presents itself in gradually-increasing proportion, as the Chyle slowly passes along the Lacteal vessels, and through

the Mesenteric glands, towards the termination of the Absorbent system in the Venous; and it is also found in the fluid contents of that other division of the Absorbent system, the Lymphatic apparatus, which is distributed through the body at large, and which seems to have for its chief office to take-up, and to re-introduce into the circulating current, such of the particles contained in the fluids of the tissues as do not require to be at once cast-out of the body, but may be again employed in the process of Nutrition. But it is found, above all, in the Blood; the fluid whose ceaseless and rapid course through the body supplies to every element of the structure the materials of its growth and development: and the varying proportions in which it presents itself there, are evidently closely connected with the formative powers of that fluid. It is also a principal element of certain colourless *exudations*, which are poured-forth from wounded or inflamed surfaces, or which are deposited in the interstices of inflamed tissues; these exudations, when possessed of a high formative property (that is, a readiness to produce an organized tissue), are said to be composed of *coagulable* or *organizable lymph*, which is nothing more than the fibrinous element of the blood in an unusually concentrated state.—We shall first notice the Chemical properties of Fibrin; and shall then inquire into those which present the first dawnings or indications of Vitality.

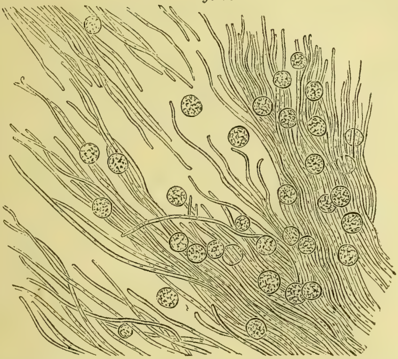
186. Like the other Albuminous compounds, *Fibrin* may exist either in solution, or in an insoluble form; but there is this important difference,—that its soluble form is not a permanent one, and cannot be maintained in any fibrinous fluid that has been drawn from the living vessels, without the addition of other substances. Insoluble Fibrin may be obtained in its purest state by whipping fresh blood with a bundle of twigs, by which operation it will be caused, in coagulating, to adhere to the twigs in the form of long, white, elastic filaments, with scarcely an admixture of foreign matter. There is reason to think that it differs from Albumen in containing a larger proportion of Oxygen; and recent experiments have shown that the proportion of Fibrin in the blood of a living animal may be increased considerably by causing it to breathe pure oxygen, or by accelerating its respiratory movements by means of an electro-magnetic current; whilst a substance resembling coagulated Fibrin in the structure of its coagulum gradually generates itself in flocculi, when a continuous stream of oxygen is passed for some time through an Albuminous liquid. It differs from Syntonin or muscle-substance, as from other albuminoid compounds, in not being dissolved by water acidulated with 1 per cent. of hydrochloric acid; being merely caused to swell-up into a gelatinous mass, which contracts again when more acid is added. When dried in vacuo or at a gentle heat, it becomes translucent and horny; and in this

condition it closely resembles coagulated albumen. It further resembles that substance in being soluble in very dilute caustic alkali and in phosphoric acid; and the solutions exhibit many of the properties of the similar solutions of albumen. When the Fibrin of venous blood is triturated in a mortar with a solution of nitrate of potash, and the mixture is left for twenty-four hours or more at a temperature of from 100° to 120°, it becomes gelatinous, slimy, and eventually entirely liquid. In this condition it exhibits all the properties of a solution of Albumen which has been neutralized by acetic acid; for it coagulates by heat; it is precipitated by alcohol, corrosive sublimate, &c.; and, when largely diluted, it deposits a flocculent substance not to be distinguished from insoluble albumen. The Fibrin of arterial blood, however, cannot be reduced to the fluid form by solution with nitre; and this appears to be due to its oxidized condition; for in a solution of Venous fibrin in nitre, contained in a deep cylindrical jar, and having its surface freely exposed to the air, a fine flocculent precipitate is gradually seen to form; and this, when collected, is found to have the properties of arterial fibrin. Fibrin, like Albumen, unites with acids as a base, forming definite compounds; and with bases as an acid. It also possesses the property of uniting with the earthy phosphates; of which from 0·7 to 2·5 per cent. are found in the ash that is left after its combustion.— There can be no doubt that it is formed in the blood, and in the other fluids in which its presents itself, at the expense of Albumen; and though we know little of the means by which this transformation is effected, yet several circumstances point to the conclusion that a higher degree of oxidation is an essential condition of the change.

187. We see, then, that when considered in its simply-Chemical relations, Fibrin is very closely related to Albumen; and that the chief point of obvious variation is the *spontaneous* coagulation of the former when removed from the living body. There is, however, in the structure of the coagulum itself, a most important difference; for instead of consisting of a homogeneous structureless mass, or of a simple aggregation of minute granules, it is found by the Microscope to present an appearance as of imperfectly defined fibres crossing one another in every direction. In the ordinary coagulum or clot of Blood, these fibres do not present any great degree of firmness; they may be hardened, however, by boiling; and their arrangement then becomes more definite. They may be seen much more clearly, however, in the 'buffy coat' of Inflammatory blood (Fig 3), in which there is not only an increased proportion of Fibrin, but the Fibrin itself seems to have undergone a higher elaboration, that is, to have more completely undergone the peculiar change (whatever may be its nature) that caused it to manifest its distinctive attributes. In

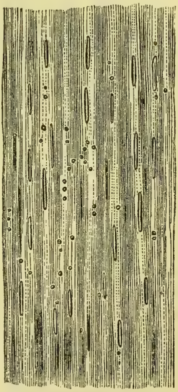
this state, the process of coagulation is unusually slow; the clot formed by the fibrous tissue is much more solid; and it continues

Fig. 3.*



for some hours, or even days, to increase in firmness, by the mutual attraction of the particles composing the fibres, which causes them to contract and to expel the fluid contained in their interstices.—After remaining in the coagulated state for a certain length of time, the Fibrin undergoes a further change, which is evidently the result of decomposition; the coagulum becoming soft, and exhibiting appearances of putrefaction. This takes place the more rapidly, as the first coagulation was less complete. Thus in the imperfectly elaborated Fibrin of the Chyle, the coagulum is sometimes so incomplete that it does not separate itself from the serum, and liquefies again in half an hour. In certain states of disease, the solidifying properties of the Fibrin are very much impaired, so that it soon liquefies and decomposes; and in these cases, there is scarcely any trace of the characteristic fibrous arrangement of the

Fig. 4.†



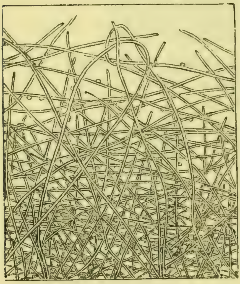
* Portion of buffy coat of blood; showing fibrous arrangement (rendered more distinct by corrosive sublimate) and colourless corpuscles.

† Nucleated blastema.

particles.—On the other hand, the fibrinous coagulum of inflamed blood, as it is more solid, is also more persistent, than that of ordinary blood; and the greatest persistency of all is seen in the fibrous network formed by exudation, as in the cases to be next mentioned.

188. The most perfect fibrous structure originating in the simple coagulation of Fibrin, is exhibited in those Exudations which take-place either from inflammation, or from a peculiar formative action destined to repair an old tissue or to produce a new one. Thus in Fig. 4 is shown the appearance of the 'nucleated blastema' effused into the theca of a tendon divided by subcutaneous incision; in which an incipient *fibrillation* is seen. In a more advanced stage of this process, such as is seen in the false membranes formed by the consolidation of a fibrinous exudation from the surface of an inflamed serous membrane, the fibres are as definite as in Fig. 3. And in Fig. 5 is displayed a similar fibrous structure (in which, however, the fibres have more of a reticulated arrangement), which incloses the fluid contents of the Fowl's egg, and enters into the composition of the shell itself. As the ovum (which, at the time of its quitting the ovarium, consists of the yolk-bag only) passes along the oviduct of the parent, it receives a coating of albuminous matter, of which layer after layer is thrown-out by the vessels of the oviduct. When a sufficient supply has thus been furnished, it appears that fibrinous instead of albuminous matter is poured-forth; and this, in coagulating, forms a very thin layer of fibrous tissue, which envelopes the albumen. Layer after layer is gradually added; and at last, by the superposition of these layers, that firm tenacious membrane is formed, which is afterwards found lining the egg-shell. The process is then continued, with this variation, that carbonate of lime is also secreted from the blood in a chalky state; and its particles lie in the interstices of the fibrous network, and give it that solidity which is characteristic of the shell. If they be removed by the agency of a weak acid, or if the bird be not sufficiently supplied with lime at the time of laying, the outer membrane has the same consistence as the inner: and either may be separated, after prolonged maceration, by dexterous

Fig. 5.*



* Fibrous membrane lining the Egg-shell, and forming the animal basis of the shell itself.

manipulation, into a series of layers of a fibrous *matting*, like that represented in Fig. 5.—The completeness of the production of such a fibrous tissue depends in part, as we have seen, upon the degree of elaboration which the fibrin has undergone; but in great part also upon the nature of the surface on which the coagulation takes place. Thus we never find so perfect a membrane formed by the consolidation of the Fibrin out of the living body,—on a slip of glass for example,—as when it takes-place on the surface of a living membrane, or in the interstices of a living tissue. This may perhaps be accounted for by the fact, that the coagulation takes place much more slowly in the latter case than in the former, and that the particles may thus have more time to arrange themselves in the definite *fibrillation* which seems to be their characteristic mode of aggregation: just as *crystallization* takes-place best when the action is slow; and as a substance whose particles would remain in an amorphous or disunited form if too rapidly precipitated from a solution, may present a most regular arrangement when they are separated from it more slowly. Of this view it would seem to be a confirmation, that the most perfect fibrillation out of the body is usually seen in those cases in which coagulation takes place least rapidly.

189. The conditions under which the spontaneous coagulation of Fibrin takes place, are best known from the observation of that process as it occurs in the Blood; and although this fluid, as we shall hereafter see, is of a very complex nature, yet as the Fibrin alone is concerned in its coagulation, and as that act would seem to take place in the same manner as if no other substance was present, there appears to be no objection to the employment of the phenomena of Blood-coagulation as the basis of our account of the properties of Fibrin.—There can be no doubt, from Microscopical observation of the circulating Blood, that Fibrin is in a state of perfect *solution* in the fluid; and in this condition it remains, so long as it is in motion in the living body. That its fluidity, however, does not depend only upon its movement, is evident from two facts;—first, that no kind of motion seems effectual in preventing the coagulation of the blood, after it has been drawn from the vessels;—and second, that a state of rest within the living body does not immediately produce coagulation; a portion of blood, included between two ligatures in a living vessel, remaining fluid for a long time; whilst blood that has been reduced to a state of complete stagnation by inflammatory action, is often found in a fluid state after some days. On the other hand, it seems certain that the state of vitality of the parts with which the blood is in contact, has a great influence in preserving its fluidity; thus it has been found that, if the brain and spinal cord of an animal be broken-down, and by this measure the vitality of the body at large be lowered, clots of blood are formed in their

trunks within a few minutes. Nevertheless, a mass of blood effused into any of the principal cavities of the living body, undergoes coagulation almost as soon as it would in a dead vessel; but this may be accounted-for by the very small surface which is in contact with the blood, as compared with the mass of the latter; and when the effusion takes-place into the interstices of the tissues, the blood often preserves its fluidity for many days or even weeks. It must be remembered that the circulating blood is continually being subdivided into countless streams; and that each of these passes through the living tissue, in such a manner that all its particles are in close relation with the living surface. Moreover it is probable that the form of matter which we term Fibrin, never remains long in that condition in the ordinary state of the system; being continually withdrawn by the nutritive processes, and as continually reformed from the Albumen. Hence we may regard the state of motion through living vessels, as essential to the permanent continuance of fibrin in the fluid form.

190. The length of time, however, during which Fibrin may remain uncoagulated, after it has been withdrawn from the living body, varies according to several conditions; some of which are not well understood. In the first place, as already remarked, the more elaborated and more concentrated the condition of the Fibrin, the more slowly does it usually coagulate. Thus when a large quantity of blood is drawn at one bleeding into several vessels, that which flows first takes the longest time to coagulate and forms the firmest clot; whilst that which is last drawn coagulates most rapidly and with the least tenacity. The coagulation is accelerated by moderate heat, and retarded by cold; but it is not prevented even by extreme cold; for if blood be frozen immediately that it is drawn, it will coagulate on being thawed,—thus preserving its vitality, in spite of the freezing process, like the organized structures of many of the lower animals. Again, the coagulation is accelerated by exposure to air; but it is not prevented, though it is retarded, by complete seclusion from it. Various Chemical agents retard the coagulation without preventing it; this is the case especially with strong solutions of neutral salts, the mixture of which with blood keeps it in a fluid state for an apparently unlimited period; whilst a dilution of the mixture is followed by coagulation of the fibrin. The coagulation is not so firm, however, or the fibrillation so perfect, after the use of these; and there can be no doubt that they modify the properties of the fibrin by acting chemically upon it.

191. The coagulating power of Fibrin may be destroyed by various causes operating within the living body, so that the blood remains fluid after death. These may be classed under three heads. In the first place, the coagulability may be destroyed by substances introduced into the blood from without; which have

he power of acting in the manner of *ferments*, and which occasion n obvious chemical change in its condition. Such is the case in hose severe forms of Fever which are termed *malignant;* and specially those which result from the contact of putrescent matter, s Glanders, Pustule maligne, &c. Secondly, it may be impaired r altogether destroyed by morbid actions originating in the sysem itself, and depending upon irregular nutrition or imperfect xcretion; thus the blood has been found fluid after death in evere cases of Scurvy and Purpura, also in cases of Asphyxia consequent upon the retention of carbonic acid in the blood), and n the bodies of overdriven animals. The same result may follow, Thirdly, from violent shocks or impressions which suddenly estroy the vitality of the whole system at once; these may be uch as are obviously capable of producing a chemical or mechaical change, as in the case of death by Lightning or by a violent Electrical discharge; or they may act through the Nervous Sysem, in a manner not yet clearly understood, as when death results rom concussion of the brain, from a blow upon the epigastrium, rom violent mental emotion, or from a coup de soleil.—It is not o be supposed that the non-coagulability of the Blood is a pheomenon by any means invariable under the foregoing circumtances; but it has been occasionally observed in all of them. We nust not mistake for the *absence of coagulating power*, the remarkble *retardation of the act of coagulation* which sometimes occurs. Thus, the blood is occasionally found in a fluid condition in the odies of persons that have been dead for some days; and yet, vhen withdrawn from the vessels, it coagulates.*

192. The recent enquiries of Schmidt have thrown a good deal f new light upon the conditions under which Fibrinous coagulaion takes place. It was long since observed by Dr. A. Buchanan hat the fluid of hydrocele, although not coagulable *per se*, undergoes coagulation when fluid blood-serum is mingled with it, or vhen a piece of washed blood-clot, of buffy coat (even after this ad been dried and preserved for several months), of muscle, skin, onnective tissue, spinal marrow, &c., is placed in it; and it has een found by Schmidt that this is the case also with the fluid of ericardial, peritoneal, and other so-called serous effusions. He as also ascertained that the addition of red corpuscles is a powerul promoter of coagulation; so that if a few corpuscles be added o a small quantity of the exudation under the microscope, they ct as centres of coagulation. That they exert this power in virtue f their contents, and not by serving as mere nuclei for solidifica-

* It has not been thought requisite here to discuss the hypothesis of Dr. Richardson, that the coagulation of the Blood depends upon the escape of mmonia; the invalidity of this hypothesis having been demonstrated by ater enquiries. The whole subject is very fully and ably discussed in the Natural History Review," April, 1864.

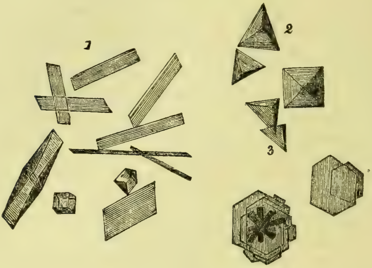
tion, appears from the fact that the same power is exercised by blood-crystals (§ 193), whilst other small particles, such as finely divided silica, charcoal, &c., have no effect whatever. Hence it appears that in these cases the coagulation of the exudation depends on the introduction into it of some foreign substance capable of exerting a *fibrino-plastic* influence; the material of the exudation not being itself fibrinous, but *fibrinogenous*, or capable of generating fibrin.—The further researches of Schmidt have led him to the conclusion that the 'fibrinoplastic' substance is nothing else than *Globulin;* an albuminous compound which had been previously discovered by Berzelius in the crystalline lens, and had been supposed by him to be the albuminoid constituent of blood-corpuscles. This substance may readily be obtained from blood-serum, by passing carbonic acid through it, or by adding to it a small quantity of very dilute acetic acid; and it may be obtained in like manner from a solution of blood-crystals, from chyle and lymph, from saliva, synovia, and the fluid of connective tissue and from the fluids of the eye. It is a white amorphous precipitate, insoluble or nearly so in distilled water, but rendered soluble by passing a stream of oxygen or atmospheric air through water holding it in suspension. It is very soluble both in dilute acids and dilute alkalies; and may be thrown down from each solution by carefully neutralizing it with the other, being redissolved by the slightest excess of either. Neither its acid nor its alkaline solution can be coagulated by heat; but when it is suspended in distilled water and boiled, it becomes flocculent, enters into an insoluble modification, and then resists the action both of acids and alkalies, even in a concentrated form. It is soluble in the alkaline carbonates and neutral salts, and can be precipitated from these solutions when sufficiently diluted, by the action of carbonic acid. It is insoluble in alcohol and ether. Globulin may be dried or preserved in alcohol for a long time, without losing its fibrino-plastic properties; but they disappear when it is exposed for any length of time to the action of the atmosphere, especially at an elevated temperature, and are destroyed at once by a heat of 160° Fahr. The fibrino-plastic power is strongest when the globulin is held in an extremely dilute alkaline solution; it is weakened in proportion as alkali is added to this; and is altogether suspended, on the other hand, when the solution is acidified. It again becomes active, however, when the globulin has been thrown down by neutralizing the acid or the excess of alkali, and has been washed and redissolved in the proper amount of alkali.—The *fibrinogenous* substance has not been so satisfactorily isolated. By saturating hydrocele-fluid, or some other similar effusion, with carbonic acid, an amorphous deposit is obtained, which, when dissolved by dilute alkali, gives a distinct though slight coagulum with blood-serum, but which gives scarcely any or none at al

when mixed with solution of Globulin. The best coagulation is obtained by operating with the natural factors,—the fluid pressed out from a blood-clot, and untouched hydrocele fluid; the next best with artificial globulin and exudation; that of blood-serum and artificial fibrinogen is much inferior; and that of artificial globulin, and artificial fibrinogen is *nil* or almost so. This may fairly be attributed to the unstable condition of the substances concerned; which are probably continually undergoing change during life, and can scarcely be separated from their combinations without undergoing some alteration.—From the foregoing results it seems most probable that the influence of living surfaces in keeping the blood fluid is in some way exerted by a change continually taking place through their instrumentality in the globulin; and that the coagulation of blood withdrawn from them is due to the unrestrained action of the globulin it then contains upon its fibrinogenous constituent. When the blood has remained long in the vessels after systemic death, it does not coagulate nearly as firmly as that which has been withdrawn during life or shortly after death; and pericardial or peritoneal plasmata, when taken from a freshly-killed animal, set into a firm clot in a few minutes, although, if left in the body for some time, they do not clot at all unless globulin be added. Hence the coagulability or non-coagulability of the blood or of fibrogenous effusions seems to depend upon the presence or absence of globulin; and of this substance there appears to be a continual formation and destruction during life, and for some time after the death of the body at large.

193. The Red Corpuscles of the blood may be made, by a peculiar treatment, to yield a substance closely allied to the albuminous compounds in composition, but differing from them in the very singular property of assuming a *crystalline* form. The most ready method of obtaining blood-crystals is to add to a drop of blood on a slip of glass either water, ether, or chloroform; and then allow the mixture to evaporate, during which process a formation of crystals will take place. They present considerable varieties, not merely of shape, but of system, in different animals; thus in Man and the Carnivora generally they have a prismatic form, whilst those of the Rat and Mouse are tetrahedral, those of the Squirrel hexagonal plates, and those of the Hamster rhombohedral (Fig. 6). They are usually deeply tinged with the peculiar colouring matters of the blood, and cannot be freed from it without much difficulty. They are unstable, deliquescing on exposure to the air, and soluble in water. Acetic acid and ammonia dissolve them readily; but they are insoluble in alcohol. The relation of the substance of which these crystals are composed, and which has been termed *Hæmato-crystallin*, to the Albuminous compounds and especially to the *Globulin* just described, has not as yet been fully made out. It resembles Albumen, not only in the proportions of

C, H, N, and O, which it contains, but also in coagulating from its solution when heated to a temperature of between 140° and 150°; it differs from Albumen, however, in not being precipitated from its solution by nitrate of silver, bichloride of mercury,

Fig. 6.*



chloride of zinc, or subacetate of lead, whilst it is thrown down by protonitrate of mercury and bichromate of potass.—The peculiar colouring matter which is united with the hæmato-crystallin in ordinary blood-crystals, has not yet been separated in a soluble form; the *Hæmatin* of Mulder being insoluble in water, or nearly so, though readily dissolving in dilute alkaline solutions, and also in alcohol when mixed either with sulphuric acid or with ammonia. This solution, even when diluted, has a dark colour; and possesses all the properties of the colouring matter of venous blood. Hæmatin differs completely from the Albuminous compounds in the proportions of its components, especially in the large amount of Carbon which it contains; it is also peculiar, in having an equivalent of Iron so intimately associated with the C^{14}, H^{8}, N, O^{2}, of which (according to Mulder) it is composed, as apparently to form a true constituent of the substance. This iron is not withdrawn by digestion of Hæmatin for several days in dilute sulphuric or muriatic acid, which would dissolve it out if it were but loosely blended with the other components. When Hæmatin is treated, however, with strong sulphuric acid, the iron is removed by this re-agent, the residue still retaining its characteristic hue; whence it is obvious, that, whatever other purpose the presence of Iron may serve in the Red corpuscles, it has no essential relation to their colour. In extravasated blood, Hæmatin appears to undergo a gradual change into a substance that has received the name of *Hæmatoidin*, which sometimes assumes the form of beau-

* Blood-crystals.—(1) prismatic, from *Human* blood; (2) tetrahedral, from *Pig's* blood; (3) hexagonal plates, from *Squirrel's* blood.

tiful red rhomboidal prisms. It is distinguished from Hæmatin by the absence of iron, and by its want of solubility in dilute acids and alkalies.

194. *Gelatigenous Compounds.*—A large proportion of the Animal fabric is made up of tissues whose functions are purely *mechanical*, —namely, the *Osseous* substance of the skeleton, the substance of the *Cartilages* interposed between adjacent bones to deaden the shock of their mutual impact, and the *Fibrous* substance of the Ligaments that hold the bones together, and of the Tendons that communicate to them the motor power of the muscles. These tissues contain little or no albumen; but yield, on continued boiling in water at 212°, or more rapidly when digested under pressure at a higher temperature, either the substance known as *Gelatin*, or another, *Chondrin*, that is closely allied to it. The composition of Gelatin is much simpler than that of the Albuminous compounds, so far, at least, as regards the number of atoms of its several elements; for it consists of C^{13}, H^{10}, N^{2}, O^{5}. This composition is the same, whether the Gelatin be obtained from isinglass, from fibrous membranes, or from bones. The distinctive characters of Gelatin are its solubility in warm water, its coagulation on cooling into a uniform jelly, and its formation of a peculiar insoluble compound with Tannic acid. Gelatin is very sparingly soluble in cold water; though prolonged contact with it will cause the Gelatin to swell-up and soften. Its power of forming a jelly on cooling is such, that a solution of one part in 100 of water will become a consistent solid. And its reaction with Tannic acid is so distinct, that the presence of one part of Gelatin in 5000 of water is at once detected by infusion of galls. —There can be no doubt that Gelatin does not exist *exactly as such* either in the Osseous or in the Fibrous tissues; since none can be dissolved out of them by the continued action of cold water, and their organic basis does not enter into combination with tannic acid until it has undergone conversion. It has, indeed, been commonly stated that the action of Tannin is the same on the organized tissue of Skin, as on the Gelatin extracted from it by boiling; but this is certainly not the case. A fresh skin cannot be converted into leather by the most complete impregnation with tannic acid; and a gradual change must be effected in its substance by incipient decomposition, before the tanning process can take effect. This change seems analogous to that which is produced by prolonged boiling or digestion, alike in the organic matrix of Bone (§ 285) to which it is convenient to give the name of *Ostein*, and in the Fibrous tissues, of which also it seems probable that Ostein is the basis. As chemical analysis shows no difference in ultimate composition between Ostein and Gelatin, these two substances may be regarded as isomeric; and the difference between them would seem rather to lie in the mode of aggregation

of their particles, than in their essential constitution. For the indications of organic structure in the wall of the Fish's air-bladder (which, when cut into shreds and dried, is known as Isinglass) are very slight, and gelatin may be obtained from it by hot water, even without boiling: in the organic basis of Bone left after maceration in dilute acid, a fibrous arrangement is discernible with difficulty, and for the conversion of its ostein into gelatin a short boiling only is required: whilst the definitely-fibrous tissue of the Skin is only resolvable into gelatin by a much more prolonged ebullition. — The substance termed *Chondrin*, obtainable from Cartilages by a still more prolonged boiling than is required for obtaining gelatin from bone or skin, agrees with gelatin both in ultimate composition and in general properties, but differs from it in being precipitated by hydrochloric and acetic acids, alum, acetate of lead, and protosulphate of iron, which do not disturb a solution of gelatin. — It is curious, that, in proportion as Cartilages become *fibrous* (§ 257), they yield Gelatin inssead of Chondrin on boiling; and the same change takes place in Cartilages that are undergoing ossification. From this and other considerations, it seems likely that Chondrin stands as an intermediate term between the Albuminoid compounds and Gelatin proper.

195. It is not yet known how the Gelatinous Compounds are produced in the Animal body. There can be no doubt that they may be elaborated from Albumen; since we find a very large amount of Gelatin in the tissues of young animals, which are entirely formed from albuminous matter; and also in the tissues of herbivorous animals, which cannot receive it in their food, since Plants yield no substance resembling gelatin. And although Carnivorous animals will receive it ready formed as part of their aliment, yet there is very strong reason to believe that it does not serve even for the nutrition of the gelatinous tissues, which seem all to be formed at the expense of the plasma of the blood. It may be considered as certain that it is incapable of being converted into Albumen; and consequently that it can never be applied to the nutrition of the albuminous tissues (§ 429).—If Gelatin be boiled for some time in caustic potash, it is decomposed, with an escape of ammonia; and two new compounds, *Leucin*, and *Glycin* or gelatine-sugar, are generated. The first of these substances is of special interest, from the fact that it may be generated by the very same means from Albumen; thus showing that notwithstanding the marked differences in the composition and characters of these two substances, there is a certain similarity in the arrangement of their ultimate elements. Leucin is a neutral crystalline substance, which forms colourless scales destitute of taste and odour: it is soluble in water, and sublimes unchanged. Its formula is C^{12}, H^{12}, N^{1}, O^{4}. The other product of the decomposition of Gelatin by alkalies, viz.—Glycin or gelatin-sugar,

has a strong sweet taste, and is very soluble in water, from which it may be crystallized like ordinary sugar. Its composition is comparatively simple, being C^4, H^5, N^1, O^4. The chemical relations of this substance are very important; and it is of great physiological interest, from the circumstance that it is obtainable from components both of the Biliary and of the Urinary excretion, viz.—Glycocholic acid and Hippuric acid.

196. The *Horny* compounds constitute a class still more distinguished by their permanence than the Gelatigenous, and nearly allied to them in composition. They are found in the Epidermis and epidermic tissues, such as nails, hoofs, hair, horn, and feathers; all of which agree closely in ultimate composition, the proportionals of C H N O being nearly the same in them as in Gelatin. They are insoluble in water, alcohol, and concentrated acetic acid; when treated with dilute alkalies they swell-up without dissolving; but after being digested in hot water they are dissolved by caustic potass, from which they may be precipitated by acids. By long-continued boiling in water, a change is effected in their composition, ammonia being given off, and a solution being formed which does not gelatinize on cooling. They yield Leucin when boiled for some time in Sulphuric acid.

197. Although the foregoing may be regarded as the essential components of the Animal body, yet a great variety of other substances are also found in it, which are *derivatives*, more or less direct, from those already described. Some of these occur in the products of Secretion which are prepared to serve particular purposes in the economy; such are the *ptyalin* of Saliva, thé *pepsin* of the Gastric juice, and the *mucin* of Mucous membranes; all which appear to be nearly related to Albumen in composition, but to have undergone some change whereby their properties have been considerably modified. But there are others which are generated within the body by the disintegration of its proper components, and are destined to be cast out of it by the processes of Excretion; of these, we have typical examples in the *urea*, *uric*, and *hippuric acids*, and other organic compounds found in the Urine, which contains nearly all the nitrogen that is eliminated from the body; whilst in the peculiar *resinous acids* and other components of the Bile, we have a class of substances that seem intermediate between these and the preceding, being separated from the blood as excrementitious, but being destined to certain uses in the economy before being finally cast forth from it. The composition and properties of these various substances will be more appropriately noticed in the description of the Secretions and Excretions of which they are respectively the characteristic ingredients. But it will be convenient here to state in general terms what may be considered as the *ultimate results* of those processes of disintegration and decay to which the Animal body is subject,

as represented in the several excretions.—The most important of these products of disintegration are *Carbonic Acid*, *Water*, and *Urea*. The quantity of Carbon which passes-off from the Lungs and Skin, in combination with Oxygen taken in from the Air, is under ordinary circumstances as much as 3,880 grains; whilst that which is eliminated by the Urine and Fæces together is only equal to 460 grains, or but little more than one-tenth of the whole. Of Water, besides the large proportion ingested either *per se* or in combination with other components of the food, there is an actual formation in the system, by the union of Hydrogen furnished by the food with Oxygen mostly derived from the air, to the extent of about 1,750 grains daily. Of Urea and other highly-azotized compounds in the Urine, the average daily excretion is about 520 grains; and of this, *nearly one-half* consists of Nitrogen. This element is not eliminated through any other channel save the Fæces, of which it forms a very insignificant proportion. Further, after having left the body, Urea very readily undergoes decomposition, especially when in contact with the 'ferment' supplied by the mucus of the bladder always contained in urine; and by combining with two equiv. of Water is resolved into Carbonate of Ammonia, as follows:—

$$\left.\begin{array}{lr} \text{1 Urea} \quad . \quad . & C^2\,H^4\,N^2\,O^2 \\ \text{2 Water} \quad . \quad . & H^2 \quad O^2 \\ \hline & C^2\,H^6\,N^2\,O^4 \end{array}\right\} = \left\{\begin{array}{lr} \text{2 Ammonia} \quad . \quad . & H^6\,N^2 \\ \text{2 Carbonic Acid} & C^2 \qquad O^4 \\ \hline & C^2\,H^6\,N^2\,O^4 \end{array}\right.$$

Thus, as already mentioned (§ 15), we find that the continual reproduction of Carbonic Acid, Water, and Ammonia, which is effected by the incessant disintegration of the Animal body, restores to the Inorganic world the very substances from which the materials of their Organic Compounds were at first drawn.—The proportion of excrementitious matter that passes-off in any other form is comparatively insignificant; the amount of the non-azotized solids of the Urine (excluding the Salts) being less than 100 grains, and that of the solids of the Fæces (of which only a small proportion is really excrementitious, the greater part consisting of matters which have never been digested) being under 600 grains daily.

CHAPTER IV.

OF THE ELEMENTARY PARTS OF THE ANIMAL FABRIC.

1. *General Considerations.*

198. Before proceeding to take to pieces (as it were) the complex structure of Man or any one of the higher Animals, we shall find it advantageous to enquire what are the simplest conditions

under which Animal life can be maintained; since it is in this manner that we can best distinguish what is *universal* from what is *special*, what is *essential* from what is merely *accessory*. There might seem at first sight to be so little in common between the lowest and the highest types of Animal existence, that no comparison can be instituted between them. But, when we come to study the developmental history of the constituent parts of the higher organisms, we find that there is such an essential correspondence between the earliest phase of their existence and the permanent condition of the lowest, as shows that a fundamental unity exists throughout; that unity consisting in the universal prevalence of a semifluid substance possessing distinctively vital endowments, which constitutes the entire body of the lowest Animals, and which gives origin to all the special forms of structure that we find in the highest. This substance was termed *sarcode* by M. Dujardin, who first drew attention to its peculiar nature as exhibited in Animalcules, &c.; among those who have studied its characters in the higher Animals it is commonly known as *blastema* or 'formative material'; while Dr. Beale, who has greatly extended our knowledge of its endowments and of its fundamental importance in the operations of Nutrition, has designated it by the term *germinal matter*. The Student will do well to remember that the substance to which these and other terms are applied, is one and the same; and it may be added that it is essentially identical with the *protoplasm* of the Vegetable, the movements of which (giving rise to the 'cyclosis' that is so well seen in the interior of the cells of *Vallisneria*, *Anacharis*, *Tradescantia*, or the elongated tubular cells of *Chara**) are closely paralleled in the tribe of Animals of which some account will now be given.

199. In the greater portion of the class to which the name *Rhizopoda*† is now applied, we find the whole living body to be composed of a semifluid 'protoplasm' presenting neither constancy

* See the Author's Manual entitled "The Microscope and its Revelations," §§ 216 and 246—248.

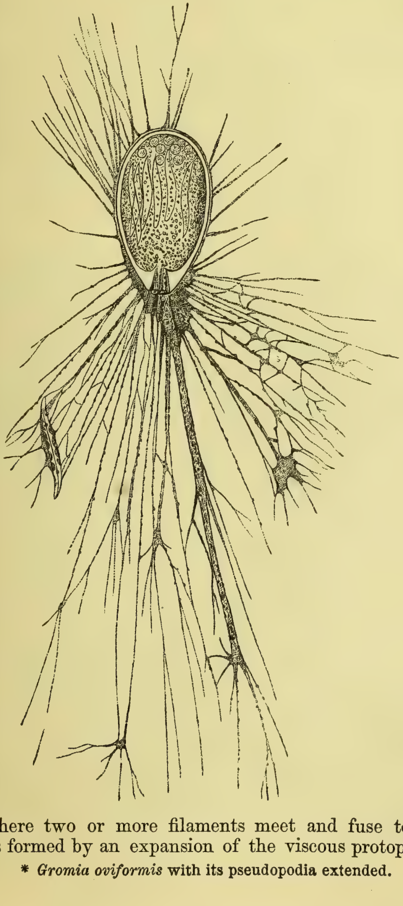
† This term was first applied in 1835 by M. Dujardin to a group of minute animals, some of the shell-less forms of which (e.g., *Amœba*) had been previously included among Animalcules; whilst the greater proportion, which bear those minute chambered shells known as *Foraminifera*, had been erroneously ranked with *Nautilus* and its allies among Cephalopod Mollusks. The general result of M. Dujardin's observations was, that the body consists, alike in the naked and in the testaceous forms, of the homogeneous substance which he designated as *sarcode*; that this is capable of extending itself into *pseudopodia* (false feet) which assume various forms, sometimes subdividing like roots,—whence his designation of the class, *Rhizopoda* 'root-footed'; and that there is neither mouth for the introduction of food, nor digestive cavity for its reception, the alimentary particles laid hold of by the pseudopodia being received into the midst of the sarcode body, to which they impart their nutritive material, and from any part of the surface of which their indigestible remains are extruded.

of form, nor any such differences in the consistency of its parts as is requisite to constitute what is understood as 'organization' even of the lowest degree and simplest kind. The Physiologist, in fact, has here a case not admitting of any other interpretation, in which those vital operations that he is accustomed to see carried-on by an elaborate apparatus, are performed without any special instruments whatever;—a little particle of apparently homogeneous jelly changing itself into a greater variety of forms than the fabled Proteus, laying hold of its food without members, swallowing it without a mouth, digesting it without a stomach, appropriating its nutritious material without absorbent vessels or a circulating system, moving from place to place without muscles, feeling (if it has any power to do so) without nerves, propagating itself without genital apparatus, and in many instances forming shelly coverings of a symmetry and complexity greater than are found in any other testaceous animals.—The general features of the group are characteristically exhibited in *Gromia* (Fig. 7), some forms of which inhabit fresh water, whilst others are marine. The sarcode-body of this minute animal is invested by a yellowish brown membranous 'test' of ovoidal shape, the long diameter of which is commonly from 1-10th to 1-12th of an inch; this looks to the eye, when the animal is at rest, very much like the egg of a Zoophyte or the seed of some aquatic plant; and its real nature would not be suspected until the animal extends its pseudopodia, creeping about by their contractile action, and mounting along the sides of the glass vessel that contains it. This 'test,' which is composed of a substance that seems chemically related on the one hand to the *Cellulose* of Plants, and on the other to the *Chitine* of Insects, has a single round orifice of moderate size, through which the sarcode-body can extend itself into the surrounding medium. When the animal is in a state of rest, the whole of this body is drawn within the test; and when its activity recommences, single fine processes are first put forth, which move about in a sort of groping manner until they find some surface to which they may attach themselves. When this attachment has taken place, new sarcode flows into them, so that they speedily increase in size; and they then elongate themselves by sending out finer ramifying processes, which, in diverging from each other, come into contact with those proceeding from other stems, and completely coalesce with them. This coalescence, which demonstrates the entire absence of any membranous envelope, forms a set of inosculations or connecting bridges between the different systems of ramifications; so that the whole becomes a complicated network, that may be described as a sort of animated spider's-web, extending to a distance of six or eight times the length of the body.

200. This network is continually undergoing incessant changes; new filaments being put forth in different directions, sometimes

rom its margin, sometimes from the midst of its ramifications, vhilst others are retracted. Not unfrequently it happens that at

Fig. 7.*



a spot where two or more filaments meet and fuse together, a lamina is formed by an expansion of the viscous protoplasm that

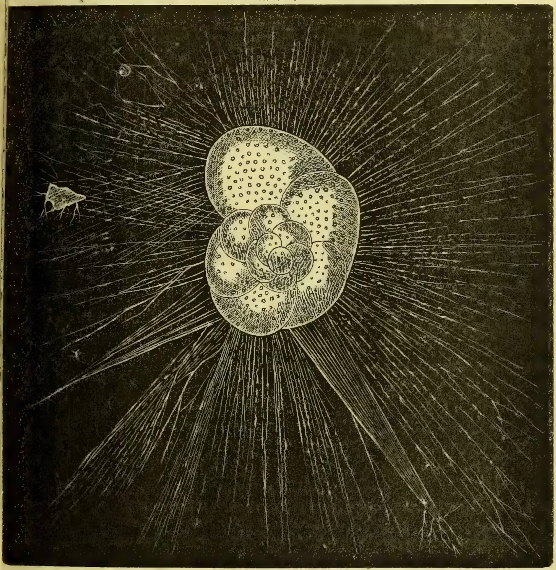
* *Gromia oviformis* with its pseudopodia extended.

flows towards this point; and from such an expansion a new set of thread-like processes are given off, as from the central body; of this, several examples are shown in the figure. It is not only, however, in the protoplasmic substance as it issues from the orifice of the test, that the pseudopodia originate; for this substance is seen to extend itself over its surface, from any part of which it may put forth pseudopodia, those developed from its posterior extremity appearing specially destined to fix it, so as to enable the anterior pseudopodia to put forth more power in the prehension of food. Any minute particle which may chance to come into contact with a pseudopodium, and which is retained in adhesion to its viscid substance, soon becomes imbedded in its protoplasm, and is subjected to the general movement to be presently described; but when a larger body is thus entrapped, a number of pseudopodia apply themselves to its surface, and a sort of flux of viscid plasma takes place towards it, until it becomes ensheathed with this substance,—as shown in the case of the Diatom entangled amongst the pseudopodia on the left side of the figure. A reflux of the protoplasm of the pseudopodia then takes place; and the body entrapped by them is gradually received into the mass of sarcode lying outside the mouth of the test, through which it passes into its interior if not too large to find admission. (Several such bodies are shown in the figure, lying in the interior of the test). From what is witnessed in other cases, it is probable that after the nutritive material afforded by the substance thus introduced has been extracted from it by the protoplasm in which it is imbedded, the indigestible residue is got rid of by an action of exactly the converse kind.—The enclosure of the body in a 'test' with a single aperture here limits the spot of ingress and egress; but in other Rhizopods which are not so invested, a mouth and anus may be extemporized (so to speak) at any part of the surface,—the absence of any limitary membrane being thus again demonstrated.

201. One of the most remarkable phenomena presented by these organisms, is the movement of granules which is continually taking place along the threads of the sarcodic network, chiefly in two directions,—from the body towards the extremities of the pseudopodia, and from these extremities back to the body again. This movement may be seen in every one of the threads; the finest filaments showing only a single current, but the larger branches presenting two streams passing in opposite directions. In the former case, the granules glide along the surface of the filament (the diameter of which is often less than that of the particles adherent to it) at distant intervals, each passing up as far as its termination, and then returning, perhaps meeting and carrying back with it a granule that was seen advancing in the opposite direction. And in the latter, it is clear that there is no distinct separation between the two streams; for granules that are going

ong steadily in one direction are sometimes observed to come) a stand, to oscillate for a time, and then to take a reverse iovement, as if they had been entangled in the opposite curint, just as is often to be witnessed in *Chara*. When a granule rrives at a point at which a filament bifurcates, it is often rrested for a time, until it is drawn into one or the other urrent; and when carried across one of the bridge-like connecions into a different band, it not unfrequently meets a current roceeding in the opposite direction, and is thus carried back to ie body without having proceeded very far from it.—No other ccount of this movement can be given, than that it depends on he vital contractility of the sarcodic substance to which the paricles attach themselves; this contractility, whilst bringing about n incessant modification in the general distribution of the pseuopodian network, occasions a change of place in its component

Fig. 8.*

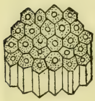


particles, which involves the motion of whatever may be adherent to them.

* *Rotalia* with its pseudopodia extended.

202. The formation of the membranous 'test' of *Gromia* obviously depends upon a kind of excretory action from the surface of the sarcode-body; and we have here a very simple case of what, there is good reason to believe, takes place in the production of most, if not all, of the 'tissues' of the higher animals. The same relation to their living contents is borne by the calcareous shells of the *Foraminifera;* the simplest forms of which resemble the 'test' of Gromia in every essential particular, save in having the organic basis consolidated by carbonate of lime. But in a large part of this group, we find the shells perforated with minute apertures disposed with great regularity, through which pseudopodial threads of great tenuity are projected in the living condition of the animal (Fig. 8); and a careful examination of the structure of such shells makes it evident that they are composed of an aggregation of tubular prisms (Fig. 9) each of which is formed by an excretory deposit round one of these pseudopodial threads. And thus, as the shell is thickened by the formation of successive laminæ, the continuity of its tubuli is maintained throughout; each new lamella, whether added internally or externally, being moulded (as it were) upon the pseudopodial prolongations of the sarcode-body which supplies its material. We seem here to have the explanation of the manner in which the Dentinal and other tubular tissues are produced in the higher animals; for although it was at one time maintained that they are formed through the intermediation of cells, there is now satisfactory reason to believe that their foundation is laid in a homogeneous blastema, analogous in all essential respects to the sarcode-body of a Rhizopod (§ 207).

Fig. 9.*



203. There is another example of the *Rhizopod* type which we may advantageously stop to notice, since it presents us with a gradational link between such *homogeneous* sarcode-bodies as we have been just considering, and what has been generally regarded the elementary form of organization,—the true Cell.—No minute inhabitant of streams or ponds is more common than the *Amœba* (Fig. 10); a creature which cannot be described by its form, since this is constantly changing, but which yet has certain very definite characters. The sarcode-body is no longer homogeneous, since its outer portion (or *ectosarc*) has an almost membranous consistence, whilst its interior (or *endosarc*) has almost the fluidity of water. The pseudopodia, which are not so much appendages, as lobate extensions of the body itself, are few in number, short, broad, and rounded, showing little or no tendency to bifurcation; and their exterior has the same semi-membranous consistence as that of the body itself, so that when two of these organs come into

* Portion of shell of *Operculina*, highly magnified.

ontact, they scarcely show any disposition even to mutual cohe-
on, still less to a fusion of their substance. No movement of

Fig 10.*

ranules can be seen to take place along their surface. An *Amœba* n a state of active vitality is almost incessantly moving from lace to place by a sort of creeping action; a pseudopodial pro-ongation being put forth, and the body being as it were drawn nto it. In the course of this movement, the Amœba encounters articles which are fitted to afford it nourishment; and these ppear to find their way into its interior through any portion of he 'ectosarc,' whether of the body itself, or of its lobose exten-ions; insoluble particles which resist the digestive process being ot rid of in the like primitive fashion. Hence it is obvious that, otwithstanding the approach to the membranous consistence pre-ented by the exterior of the sarcode-body, it is not invested by a rue membrane; and it may be further observed, that there is no lefinite line of demarcation between the 'ectosarc' and the 'en-losarc,' the one graduating insensibly into the other. Thus, then, he Amœba cannot be considered as a 'cell,' although it shows a lecided tendency towards that differentiation of cell-wall and ell-contents which is characteristic of every fully formed cell. And we shall hereafter find that its condition is in this respect losely paralleled by that of the Blood-corpuscles, both red and olourless, of Man and the higher animals; and that the latter, in articular, exhibit spontaneous changes of form, which carry out

* *Amœba,* showing at A, B, C, its modifications of form.

the parallelism with this modification of the Rhizopod type to very unexpected extent (§§ 208, 217).

204. Now it is a special characteristic of the sarcodic substan of these *Rhizopods*, that a portion of it may detach itself from t rest, and may maintain an independent existence; drawing nut: ment into its own substance, and thereby increasing, and in d time multiplying, precisely after the manner of the organism frc which it was an offset. Thus it is not unfrequently seen *Amœba*, that when a pseudopodial process or lobe of the body h been put forth to a considerable length, and has become enlarg and fixed at its extremity, the subsequent contraction of the co necting portion, instead of either drawing the body towards t fixed point, or retracting the pseudopodial lobe into the bod causes the connecting band itself to become more and more atten ated until it gives way, leaving the terminal enlargement altogetl detached; and this portion speedily shoots out pseudopodial pı cesses of its own, and behaves itself in all respects as an inc pendent *Amœba*. By a repetition of this process, a whole colo: may be (as it were) budded-off from the pseudopodial processes one individual.—The mode of multiplication which is known 'duplicative subdivision' appears to be nothing else than a mo fication of the same simple process. An annular constricti shows itself around the sarcode-body, gradually deepening so to separate the two halves by a sort of hour-glass contractio and the connecting band becomes more and more slender, until complete separation occurs between the two halves. The se ments thus formed are not always equal; and sometimes th difference in size is so considerable, that the smaller may be : garded as a mere offset from the larger, just as in the precedi case.

205. Between the simple body of these humble Rhizopods, a the complex fabric of Man and the higher Animals, there wo seem to be but little in common: yet it appears from recent ı searches that in the latter, as in the former, the process of For ation is essentially carried on by the instrumentality of *protoplasn substance*, universally diffused through it in such a manner as bear a close resemblance to the pseudopodial network of t Rhizopod; whilst the *Tissues* produced by its agency lie, as were, on the outside of this, bearing the same relation to it as t 'test' or 'shell' of a *Rhizopod* bears to the sarcode-body it inclos or as the calcareous reticulation which forms the skeleton *Echinoderms* (Fig. 67) does to the sarcodic substance which occup its interspaces.* For it appears that the smallest living 'e

* The doctrine above stated is that to which the Author has been led the comparison of the results of the recent enquiries of several British a Continental Histologists, with those of his own study of the Rhizopod a Echinoderm types. The study of the relation of the Tissues of the higl

ientary part' of every organized fabric is composed of matter in wo states; the one, which may be termed *germinal matter*, possessing the power of selecting pabulum from the blood, and of ransforming this either into the material of its own extension, or nto some product of its elaboration; whilst the other, which may e termed *formed material*, may present every gradation of character from a mere inorganic deposit to a structure of very definite rganization, but is in every case altogether incapable of self-ncrease. Thus it is on the 'germinal matter' that the existence f every form of Animal organization essentially depends; and in ll living structures the germinal matter possesses the same *general* ndowments, though its *special* powers (as shown in its products) are ery various. The entire aggregate of particles of germinal matter s capable of indefinite extension; and it may divide and subdivide nto independent portions, each of which may act as the instrument of formation of an elementary part.—The relative proportions f 'germinal matter' and 'formed material' may vary greatly in ifferent elementary parts, in the same elementary part at different eriods of its growth, and in the same tissue under different circumstances. The more rapidly growth proceeds, the larger is the bsolute amount of germinal matter produced in proportion to he amount of formed material. Rapidly growing structures are oft and easily disintegrated; on the other hand, firm dense tissues re of slow growth, and the hardened 'formed material' of which hey are mainly composed resists disintegration and change.—It s generally, if not always, on the *exterior* of the mass of the germinal matter' that the production of the 'formed material' akes place; and it is probable, that, as in the nutrition of a Rhizopod, there is a continual passage of the pabulum derived from he blood towards the central portion of each mass of germinal natter, whilst particles that have undergone elaboration move outwards, and are excreted (as it were) from its surface.—A very lefinite line of demarcation can be drawn in some instances between the 'germinal matter' and the 'formed material;' as is ndicated by the results of steeping the tissue in an ammoniacal olution of carmine, which deeply dyes the former, whilst the atter (with certain exceptions) is only stained by it. But in other cases there is the same gradation between one and the other as has been already noticed in the Amœba between the 'endosarc' and the 'ectosarc' (§ 203).

Animals to the formative substance from which they are evolved, has been specially prosecuted by Professor Beale; and as the Author considers that to him more than to any other Histologist is due the credit of having stated hat relation in its most general form, he has adopted in the following concise exposition of it the language of Professor Beale's Lectures "On the Structure of the Simple Tissues of the Human Body," delivered before the Royal College of Physicians in the Spring of 1861.

206. One of the most general forms of an 'elementary part' is that which is commonly known as a *Cell.* This, in its complete and characteristic form, consists, like the Vegetable cell, of a definite cell-wall, enclosing cell-contents; and the latter, whatever may be their special nature, include a 'nucleus,' which has long been regarded as specially related to the formative activity of the cell. But there are many objections to this use of the term 'cell,' as indicating the elementary unit of structure. There are a large number of cases in which there is no more definite investing membrane, than there is in the body of an *Amœba;* the 'elementary part' being entirely composed of a mass of protoplasm or 'germinal matter,' of which the exterior has undergone a slight consolidation, like that which constitutes the 'primordial utricle' of the Vegetable cell (§ 12). This is the case, for example, with the 'Colourless corpuscles' of the Blood (§ 214), with Granulation cells and Pus-corpuscles (§ 213), with the corpuscles of the Ductless Glands, and with cells generally in an early stage of their development; the layer of 'formed material' being here very thin, and its separation from the 'germinal matter' being far from complete. In a more advanced condition we find the 'germinal matter' limited to a smaller proportion of the interior of the cell, so as to constitute what is known as its 'nucleus'; and this is surrounded by more completely differentiated 'formed material,' which may still have no definite investment. Such appears to be the case with the Red corpuscles of the Blood of Oviparous Vertebrata (§ 216); for although these are commonly described as perfect 'cells' having a cell-wall that contains the coloured substance, no such cell-wall can be demonstrated; and the changes of form which these corpuscles can be made to undergo seem to disprove its existence. Again, in Cartilage (§ 255) we have an example in which the 'nucleus' and 'cell-contents' are completely differentiated from the 'cell-wall'; but the 'cell-wall' itself cannot be separated from what has been distinguished as the 'intercellular substance,' which is commonly regarded as the 'matrlx' wherein the true cartilage-cells are imbedded; and it would appear from a study of the history of its development, that the 'intercellular substance,' 'cell-wall,' and 'cell-contents,' are all to be regarded in the light of layers of 'formed material' successively exuded from the mass of 'germinal matter' in which the cell originated; this, on the other hand, contracting until it remains only as the 'nucleus.' The most characteristic examples of fully-formed and independent cells, are presented to us in Fat-cells (Fig. 31) and Epithelium-cells (Fig. 38); for here we have a definite limitary membrane, distinct alike from the contents of the cell and from the matrix in which the cell is imbedded; whilst the cavity of the cell is occupied by some product that has been elaborated by the agency of its mass of 'germinal matter,' which may remain to constitute its 'nucleus,' or,

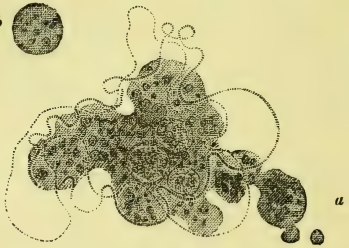
in cells that have entirely ceased to participate in any active change, may entirely disappear.

207. The relation between the 'germinal matter' and 'formed material' presents itself under a very different aspect in these *Connective Tissues* which are formed of solid *fibres*, having what are known as the 'connective tissue corpuscles' dispersed through them. The transition from the one state to the other, however, is presented by Cartilage, in which the so-called 'intercellular substance' is often as fibrous as in a tendon. And the only essential difference seems to lie in this, that whilst the segments of 'germinal matter' which form the nuclei of Cartilage-cells are completely isolated from each other (Fig. 63), each being completely surrounded by the product of its own elaborating action, those which form the 'connective-tissue corpuscles' are connected together by radiating prolongations (Fig. 28) that pass between the fibres, so as to form a continuous network closely resemblIng that formed by the pseudopodial prolongations of the Rhizopod (§ 199). These threads of communication, however, may be reduced to very narrow lines, and often disappear altogether. To these corpuscles, the Fibres, whether white or yellow, of the Connective tissues, appear to hold exactly the same relation as that which the so-called 'intercellular substance' and 'cell-walls' of the Cartilage-cells bear to their nuclei; being produced as 'formed material' from their surface, by the elaborating action they exert upon the nutrient materials which they draw from the Blood into their own substance. We shall find that an arrangement of essentially the same kind exists in Bone; for whilst its solid substance may be considered as Connective tissue solidified by calcareous deposit, the 'lacunæ' excavated in this (Fig. 70) give lodgment to a set of radiating corpuscles closely resembling those already described; and these are centres of 'germinal matter,' which appear to have an active share in the formation and subsequent nutrition of the osseous texture. In Dentine (or the substance of Teeth) we seem to have another form of the same thing; the walls of its 'tubuli' and the 'intertubular substance' being the 'formed material' that is produced from the thread-like prolongations of 'germinal matter' which proceed from the pulp (Fig. 91), and which continue during the life of the tooth to occupy its tubes;—just as in the *Foraminifera* we have seen a minutely tubular structure to be formed by a process of exudation around the individual threads of sarcode which proceed from the body of the contained animal (§ 202).

208. There can be no doubt whatever that there exist in the body of Man and the higher Animals, particles of 'germinal matter' that resemble in their power of spontaneously changing their form the sarcode-bodies of the *Rhizopods*. It has long been known that such changes of form occur in the 'Colourless corpuscles' of the Blood (§ 214); and they have been more recently

shown to occur also in the Lymph- and Chyle-corpuscles, in young Epithelial cells, in the 'nuclei' of the Corneal tissue, and especially in the peculiar corpuscles of Mucus (§ 238). Of these last an example is represented in Fig. 11, in such a manner as to show the different forms which the corpuscle was observed to assume within a minute. In the course of these changes of shape, portions of the principal mass are often observed to undergo detachment, which is seen in progress at *a*, and completed

Fig. 11.*



at *b;* and from the analogy of the *Rhizopods* (§ 204), there can be little doubt that such detached particles are capable of maintaining an independent existence, increasing in size by the assimilation of nutrient material, and in due time multiplying themselves in like manner. Sometimes, again, the entire corpuscle is seen to move along in a definite direction, for a distance equal to its own diameter or more; and in this progress it commonly leaves a sort of thread behind it, which is probably to be considered as its 'formed material.' Although such mucus-corpuscles contain nuclear particles that appear somewhat differentiated from the rest, there is no evidence that these have any peculiar share either in their movements or in their multiplication. In the Colourless corpuscles of the Blood, we seem to have a parallel to the more advanced condition which we have seen in the *Amœba* (§ 203); the exterior being of firmer consistence than its contents, and appearing to be in process of transition from the state of 'germinal matter' to that of 'formed material.' These corpuscles undergo changes of form even more remarkable than the Mucus-corpuscles; and in particular may be noticed to put-forth radiating thread-like prolongations (Fig. 12), which give them a striking resemblance to the well-known Rhizopod *Actinophrys sol.* They also have the power of progressive movement, in the course of which they leave behind

* Mucus-corpuscle from the Mucus of the throat;—*a*, a portion becoming detached by the changes of form in the principal mass; *b*, a spherule completely separated.

them threads that appear to consist of some kind of 'formed material.' It may be surmised that it is by a process of this kind

Fig. 12.*

that those Simple Fibrous Tissues are generated, of which we shall hereafter have to give an account (Sect. 3).†

2. *Of Cells, as Components of the Animal Fabric:—Free Floating Cells.*

209. The early embryo of every Animal, not excepting Man, is made up of an aggregation of cells resembling in all essential particulars those of Plants (§ 21); and although, as development advances, we observe new tissues interposed among them which are peculiar to the Animal fabric, yet even in the completed organism we still find a considerable portion to consist of the like elementary parts; and it is to be especially noticed that they are for the most part largely present in those organs which are concerned in the active performance of the *vital* functions, those which have merely *mechanical* duties to fulfil being constructed of other materials. It has even been said that *all* the vegetative functions of the body,—all the processes of Nutrition and Reproduction,—all those operations, in short, which are common to Plants and Animals,—are performed in the Animal organism, as in the Vegetable, by the agency of cells; and this doctrine is still

* Altered Colourless (or White) Corpuscle of Blood, an hour after being drawn from the finger.

† See, on the subject of this section, Dr. Duffin's excellent summary of recent observations on 'Protoplasm and the part it plays in the Actions of Living Beings'; in the "Microscopic Journal," Vol. III., N.S. p. 251.

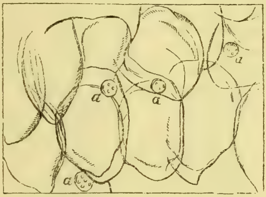
maintained by many eminent Physiologists to be true not only of healthy actions, but of various morbid operations in which the unusual development of cells possessing peculiar endowments is a characteristic feature. But it may be safely affirmed that, in the present state of our knowledge, it is only by such a wide extension of the meaning of the term as would deprive it altogether of its distinctive character, that we are justified in attributing to the 'cell' that universal agency in the Animal economy which the advocates of this doctrine claim for it; since, as we already have seen, there is ample evidence that in the lowest Animals all the functions of life are performed by a sarcodic substance not yet differentiated into cells; whilst, as will be hereafter shown, the little isolated mass of this sarcodic substance which constitutes the basis of every cell, and is the essential instrument in all vital transformations, can do its work just as well, or even better, when not included within a 'limitary membrane' or 'cell-wall.' In fact, such a limitary membrane does not exist in those corpuscles which are in a state of most active change; and its presence may be generally taken as an indication that the most active stage in the life of the Cell has already passed. And hence when the 'agency of the Cell' is spoken of, we are to understand, not that of the cell as a whole, but that of the segment of sarcodic substance or 'germinal matter' (analogous to the 'protoplasmic layer' of the Vegetable cell, § 22) which is its essential constituent.

210. With this preliminary understanding, we may proceed to enquire into the history of the Animal Cell as presented to us in its most characteristic forms. This is, in all essential particulars, the same as that of the Vegetable cell of the simplest type (§§ 21, 22); excepting in so far as the Animal cell derives its nutriment from organic compounds previously elaborated, instead of generating these, like the Plant, at the expense of Inorganic elements. It lives *for* itself and *by* itself; being dependent upon nothing but a due supply of Aliment and of Heat, for the continuance of its growth and the due performance of all its functions, until its term of life be expired. In whatever method it originates (and we shall presently see that the life of an independent cell may commence in various modes), it attracts to itself, assimilates, and organizes, the particles of the nutrient fluid in its neighbourhood; it converts some of them into the substance of its cell-wall, whilst it draws others into its cavity; in this manner, it gradually increases in size; and whilst it is itself approaching the term of its life, it may make preparation for its renewal by the development of reproductive particles in its interior, which may give origin to new cells when set-free from the cavity of their parent. So far as is yet known, the composition of the *cell-wall* is everywhere essentially the same, being either Albumen or one of its derivatives. It is in the nature of the *contents* of the cell, that (as among the

cells of Plants) the greatest diversity exists; and we shall find that the *purposes* answered by the different groups of cells in the Animal economy depend upon the nature of the products they secrete, and upon the mode in which these products are given back after they have been subjected to the action of the cells.

211. In the interior of most Animal cells, usually attached to some part of their wall, but sometimes lying free within their cavity, there may be seen a peculiar body, ordinarily of round or oval shape, which is called the *nucleus* (Fig. 13, *a*). The size of this body is more constant than that of the cell itself, being usually between 1-6000th and 1-4000th of an inch. Its aspect, however, varies greatly; for it sometimes appears quite solid, as if made up of an aggregation of granules; in other instances, it seems to be of less consistence towards the centre than it is on the surface; whilst not unfrequently, as if by a further advance in this kind of differentiation, it presents a vesicular aspect, having a consistent membrane externally, which encloses a cavity within. When this is the case, the nuclear vesicle is usually seen to contain one or more aggregations of minute granules, apparently of fatty matter, which are termed *nucleoli*. The chemical composition of the nucleus seems to be nearly the same as that of the cell-wall; but differs in this respect, that, whilst the latter is dissolved by acetic acid, the former is unchanged by it; so that acetic acid becomes a very useful re-agent for bringing nuclear bodies into strong relief, whether they are contained within cells, or are imbedded in the midst of simple fibres, or are attached to the walls of tubes, such as the membrane of Capillary blood-vessels, or the sarcolemma of Muscular fibre. From this resemblance in behaviour between nuclear bodies and Yellow fibrous or Elastic tissue (§ 226), it has been supposed that there is some special relationship between them; but there is this marked difference—that nuclei are readily dissolved by dilute alkalies, which do not affect elastic tissue.—The nucleus is shown by the dyeing it undergoes when steeped in ammoniacal solution of carmine (§ 205) to consist of an unconverted segment of germinal matter; and it appears to be the centre of the vital forces of the cell, being the part through which it specially exerts its agency on the substances brought

Fig. 13.*

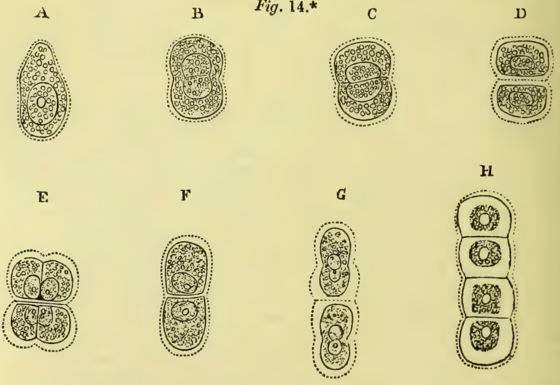


* Cells from Chorda Dorsalis of Lamprey;—*a*, *a*, their nuclei.

under its influence, and being also the essential instrument in the reproductive operation.

212. New cells may originate in one of two principal modes; either directly from a pre-existing cell, or by an entirely-new production in the midst of an organizable 'blastema.'—The development of new cells from a pre-existing cell, again, may take-place in one of two modes; either by the binary subdivision of the parent-cell, or by the production of a number of new cells in its interior; the nucleus, in each case, appearing to perform an important part in the process. Of the multiplication of cells by subdivision, we have a characteristic example in the growth of Cartilage, which repeats in adult age the process by which the development of the 'mulberry mass' takes place at the earliest period of embryonic life (§ 805). The process of subdivision commences in the nucleus, which separates itself into two equal parts, each carrying with it a like segment of the germinal matter that occupies the cavity of the cell; and by the conversion of the surface-layer of each of these

Fig. 14.*

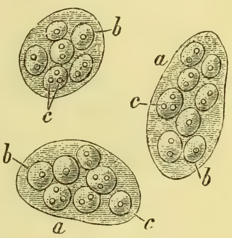


segments into 'formed material,' there arises a complete double partition between the two halves of the original cavity (Fig. 14, A—D). The process of subdivision may be again repeated, either in the same or in a contrary direction, so as to produce

* Multiplication of Cartilage-cells by duplication:—A, original cell; B, the same beginning to divide; C, the same showing complete division of the nucleus; D, the same with the halves of the nucleus separated, and the cavity of the cell subdivided; E, continuation of the same process, with cleavage in *contrary* direction, to form a cluster of four cells; F, G, H, production of a longitudinal series of cells, by continuation of cleavage in the *same* direction.

four cells, either linearly arranged (F, G, H), or clustered together (E); and this duplication may take-place repeatedly, until a large mass has been produced by the subdivision of a single original cell.—In other cases, however, the germinal matter appears to break-up at once into several segments, each of which becomes invested by a cell-wall of its own; and thus the cavity of the parent-cell may at once become filled with a whole brood of young cells, without any successive subdivision. Of this process, we frequently have examples in the case of morbid growths, in which the multiplication of cells often takes-place with great rapidity (Fig. 15).—Generally speaking, the former method seems to prevail in structures which have a comparatively *permanent* destination; whilst the latter is adopted in cases in which the life of the cells thus generated is but *transitory*, or in which they are not destined to reproduce themselves. Thus the follicles of Glands (Fig. 42) are but parent-cells, in whose wall an opening has been formed for the liberation of the cells of the new generation (which are the real instruments of the secreting process) as fast as they are formed; successive crops of young cells being generated at their blind extremity, at the expense of the fresh materials which are continually drawn from the blood.

Fig. 15.*



213. In the production of cells *de novo* in the midst of an organizable *blastema* or plastic exudation, we cannot trace with the same distinctness the instrumentality of pre-existing cells. This blastema, when first effused, presents the appearance of a homogeneous, semi-fluid substance; as it solidifies, however, it becomes dimly shaded by minute dots; and as it is acquiring further consistence, some of these dots seem to aggregate, so as to form little round or oval clusters bearing a strong resemblance to cell-nuclei. These bodies appear to be the centres of the further changes which take-place in the blastema; for if it be about to undergo development into a *fibrous* tissue, they seem to be the centres from which the fibrillation takes place; whilst if a *cellular* structure is to be generated, it is from them that the cells take their origin. Such is the mode, then, in which the development of new structures, for the filling-up of losses of substance, is

* Parent-cells, *a*, *a*, of Cancerous structure, containing secondary cells, *b*, *b* each having one, two, or three nuclei, *c*, *c*.

provided for; and it appears from the observations of Mr. Paget, that whilst the immediate *fibrillation* of the blastema takes-place in the case of effusions which are secluded from the air and which undergo organization under the most favourable circumstances, a production of *cells* takes-place when the blastema is poured-out upon the surface of an open wound, where the contact of air and other sources of irritation interfere with the organizing process, and occasion a tendency to degradation in the newly-generating tissue. The substance of 'granulations' is almost entirely composed of such cells (Fig. 16); of which the outer

Fig. 16.*

layers degenerate into pus-cells, whilst those forming the interior substance give origin to fibrous tissue (§ 227).

214. The preparation of this *blastema* or organizable material seems to be the special function of certain Corpuscles which are found floating in the Circulating fluids of animals generally; and which present us with the simplest and most independent condition of the Animal cell. These floating corpuscles are completely isolated from one another, and are consequently just as independent as the vesicles of the Red Snow or other simple cellular Plants. Indeed, in the nature of their *habitat*, we may compare them with the Yeast-Plant; for as this will only vegetate in a saccharine fluid containing vegetable albumen, so do we find that these corpuscles will only grow and multiply in the albuminous fluids of animals. These bodies are distinguished in the Blood of Vertebrated animals as the *White* or *Colourless corpuscles* (*Frontispiece*, Fig. 4), whilst in the fluids of the Absorbent system

* Granulation-cells, with imbedded capillary loop.

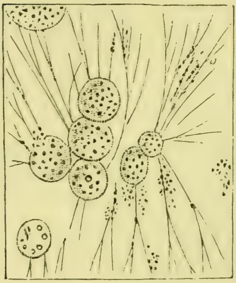
ey are known as *Chyle-* and *Lymph-Corpuscles.* Between these st and the Corpuscles which make-up the parenchyma of the -called 'Glands' of the Absorbent system, as well as of those Ductless Glands' which seem allied to them in function (CHAP. II. CT. 3), the relationship would seem to be most intimate. They e all to be regarded as cells in that earlier stage of development which there is no distinct limitary membrane around the segent of 'germinal matter' of which each is essentially composed; e only differentiation of their substance consisting in the greater nacity of their exterior and the greater fluidity of their inteor, which is a condition closely resembling that shown in *mœba* (§ 203). There is strong ground to believe that the tion of all these Corpuscles is that of elaborating organizable aterial from the crude alimentary substances first taken-up by osorption; and that after increasing and multiplying at the xpense of these, they deliver back to the circulating fluid the germinal matter' of their own substance, instead of proceeding any more advanced grade of development.

215. The Colourless corpuscles of the Blood are distinguished om the Red not merely by their colour but by their spherical orm. Their diameter is pretty uniform in different animals; eing for the most part from 1-3000th to 1-2500th of an inch. They are usually observed to contain a number of minute moleules in their interior (*Frontispiece*, Fig. 4); and at a certain stage f their development these may sometimes be seen, with a good Microscope, in active movement within the cavity. The action f a very dilute solution of potash causes the immediate rupture f these cells, and the discharge of the contained molecules. When treated with water, they swell-up (see *Frontispiece*, Fig. 5), ometimes until they burst; when, on the other hand, they are laced in strong saline solutions, they contract and become rregular in form. The action of dilute acetic acid renders their xterior more pale and transparent; whilst at the same time a eparation or partial coagulation takes place internally, forming n irregular collection of granular particles. This, however, is not to be regarded as a nucleus, being merely the result of the lteration produced by the re-agent in the substance of the coruscle. The remarkable changes of form which these bodies pontaneously undergo have been already noticed (§ 208).—The Colourless corpuscles are comparatively few in number in the Blood of the higher animals, the Red being from 200 to 300 times as numerous. In Reptiles and Fishes, however, the proportion of Colourless corpuscles is much greater, though they are nearly always considerably less abundant than the Red: but there is one curious little Fish—the *Amphioxus* or *Lancelet*,—in which the Red corpuscles are altogether wanting, its Blood being as colourless as Chyle or Lymph. In the circulating fluids of

Invertebrated animals generally, as in the Chyle and Lymph of higher animals, we find only Colourless corpuscles. And these corpuscles are found to predominate even in the blood of Man, in that morbid state which is known as *Leucocythæmia*. They abound in that colourless stratum of Inflammatory blood, the coagulation of which forms the 'buffy coat' (§ 535); and corpuscles resembling them in every essential particular are found in many fibrinous exudations (Fig. 17).

216. The *Red* Corpuscles (commonly but erroneously termed 'globules'), the presence of which is the distinguishing characteristic of the blood of Vertebrata, are minute bodies of a flattened or discoidal form, which, in Man, as in most of the Mammalia, have a distinctly circular outline (*Frontispiece*, Fig. 1), but which, in Birds, Reptiles and Fishes, with a few Mammals, are oval or elliptical in shape. The Human blood-discs, when examined in their natural condition, have somewhat concave surfaces; and as the substance of which they are composed has a higher refractive power than the liquid in which they float, each disc has the optical effect of a bi-concave lens, so that when viewed rather beyond the focus of the microscope their centres are *dark* and their peripheries *bright*, the opposite aspect being presented when they are viewed rather *within* the focus. The normal form of these discs, however, is very much altered by various re-agents. Thus if they be treated with water, or with a solution of sugar, albumen, or salt, which is of less density than the 'liquor sanguinis' (§ 525), they first become flat, and then double-convex, so that the central spot disappears; and by a continuance of this imbibition of liquid, they at last become globular, and so pale and attenuated that their borders can scarcely be distinguished. Yet, even after remaining in this condition for some weeks, they may be readily brought into view again (unless decomposition has taken place) by the application of a little iodine or corrosive sublimate. If, on the other hand, they be treated with a thick syrup, or with a strong solution of albumen or of salt, they assume a shrunken appearance; the first effect of the process being to increase the concavity,

Fig. 17.*



* Colourless cells, with active molecules, and fibres of fibrin, from Herpes labialis.

d to render the central spot more distinct. An approach to is condition is not unfrequently presented by freshly-drawn ood-discs, especially when the proportion of water in the Blood s been temporarily diminished by diuresis or excessive perspir-ion: this consisting in a granulation of the edges of the corpus-es (*Frontispiece*, Fig. 3), which disappears when the liquor nguinis is diluted with water.—The Red corpuscles of the lood of all Mammalia without exception (whether circular or al in form) are distinguished from those of Oviparous Vertebrata the absence of the *nucleus* which is universally present in the tter, usually occasioning a projection which causes their blood-scs to be somewhat bi-convex instead of bi-concave. The size the Red corpuscles is not altogether uniform in the same ood; thus it varies in Man from about 1-4000th to 1-2800th of inch. But we generally find that there is an average size, hich is pretty constantly maintained among the different indi-duals of the same species; that of the Human blood-discs may stated at about 1-3200th of an inch. In Fig. 18 are shown e proportional sizes of the Blood-discs in examples selected om each class of Vertebrate animals, accurately drawn to scale Mr. Gulliver under a magnifying power of 920 times; and e following are given by him as their average dimensions in ch case, expressed in fractions of an inch:

MAMMALIA.

1. Man	1-3200	Thickness	1-12400
2. Elephant	1-2745		
3. Musk-Deer	1-12325		
4. Dromedary	1-3254	Short diameter	1-5921
		Thickness	1-15337

BIRDS.

Ostrich	1-1649	Short diam.	1-3000
Nucleus of ditto	1-3200	do.	1-9166
Pigeon	1-2314	do.	1-3429
Humming-Bird	1-2666	do.	1-4000

REPTILES.

Crocodile	1-1231	Short diam.	1-2286
Python	1-1440	do.	1-2400
Proteus	1-400	do.	1-727

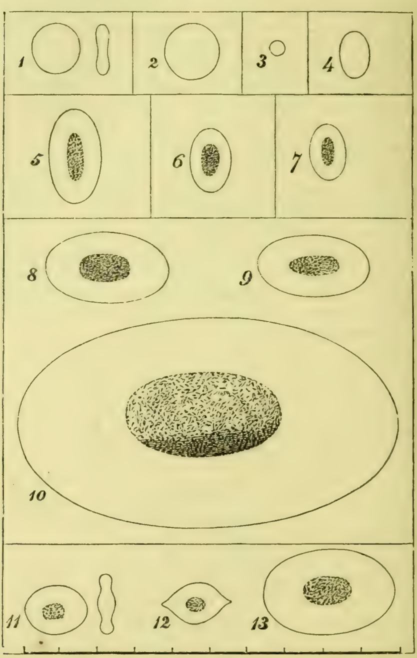
FISHES.

Perch	1-2461	Short diam.	1-3000
Pike	1-2000	do.	1-3555
Shark	1-1143	do.	1-1684

ccording to the recent estimates of Vierordt, a cubic centimètre f Human blood (which is no more than about 6-100ths of a cubic nch) contains more than *five millions* of Red corpuscles, with bout *fourteen thousand* of the White.

217. Much discussion has taken place upon the question wheth the Red corpuscles are or are not entitled to be considered *cells;* that is, whether they have a distinct cell-membrane with which the coloured contents are enclosed. Upon this point, t

Fig. 18.*

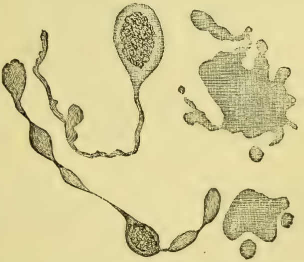


Author is disposed on the whole to agree with two of the mo recent observers, Drs. Beale and Dalton, that the evidence against the existence of a distinct membrane; notwithstandin that, as pointed-out by Dr. Roberts, the appearance even of

* Comparative sizes of Blood-Corpuscles:—1. Man; 2. Elephant; 3. Mus Deer; 4. Dromedary; 5. Ostrich; 6. Pigeon; 7. Humming-Bird; 8. Crocodil 9. Python; 10. Proteus; 11. Perch; 12. Pike; 13. Shark.

ouble membrane is shown when the Red corpuscles are treated ith tannin. In reference to this last observation it is to be borne 1 mind, that Vegetable Physiologists are now generally agreed aat what has been termed the 'primordial utricle' of the Vege-ible cell (§ 12) is nothing else than the superficial portion of the rotoplasmic layer, consolidated by the re-agents that have been pplied to bring it into view; and the same explanation may very iirly be adopted in the present instance. All the phenomena xhibited by the Red corpuscles may be explained on the idea aat the colouring substance or *Hæmato-globulin* (§ 193) is in a iscid or 'colloid' condition, its outer portion more tenacious than s inner, but not invested by a distinct membranous cell-wall; and here are several facts which do not seem to admit of any other iterpretation. The form of the Red corpuscles often changes uring their circulation in a very remarkable degree; for in the apillary vessels they sometimes become suddenly elongated, wisted, or bent, through a narrowing of the channel, such being hus enabled to pass through apertures which appear very minute a proportion to their diameter; from these effects of pressure, owever, they quickly recover themselves. But it is stated by)r. Beale, that, when carefully guarded from pressure, the Red orpuscles may be seen to undergo spontaneous changes of form Fig. 19), especially if subjected to a gentle heat of about 100°, rhich seems to render the iscid material more liquid; nd these may proceed to uch an extent as seems ncompatible with the no-ion of a definite cell-wall. 'urther, it is affirmed by he same observer, that if 'rog's or other large Red orpuscles be carefully sub-ected to sudden pressure ınder very thin glass, as or example by drawing a ıeedle-point quickly and irmly across the cover, nany corpuscles in the line of pressure will be divided into maller ones; each of the smaller ones thus separated having a pherical form, and resembling the original in colour, refractive ower, and sharpness of outline; and no appearance being dis-ernible either of a ruptured cell-wall, or of the diffusion of the luid contents through the surrounding medium. Further, when he Red corpuscles of Frog's blood have been treated with water,

Fig. 19.*



* Spontaneous changes of form in Red corpuscles of Blood of Frog.

which makes them swell-up and become more spherical (*Frontispiece*, Fig. *a*, *b*), the nucleus is seen to project more and more from the surface of the disc (*c*, *d*); and at last it frequently escapes from its envelope and becomes entirely free; in this escape no rupture of a membrane can be detected, nor is there either any diffusion of the cell-contents or collapse of the residual particle; but the process seems analogous in every essential particular to that by which the indigestible particles got rid of by the *Amœba* make their escape through its 'ectosarc' (§ 203). Again, it has been observed by Dr. Beale that the entire coloured substance of the Red corpuscles often passes into the crystalline form. "If a drop of Guinea-pig's blood obtained from a living animal be placed upon a glass slide, and covered with thin glass, it will often be observed that within an hour after it has been drawn a striking change will occur in the corpuscles. Many corpuscles exhibit sharp angles, and in a short time crystallization commences (Fig. 20). Some of the corpuscles were seen to break up

Fig. 20.*

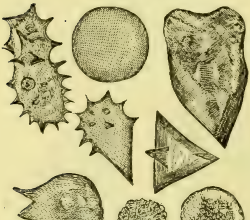


Fig. 21.†

into very small rounded portions; and after a few minutes these small particles were seen to change their form and become angular; and gradually very minute, but most distinct tetrahedral crystals were formed. In many instances a corpuscle would become very angular; sometimes exactly four angular projections were formed, and sometimes eight, but in most cases the number was irregular. After the formation of several angular projections an entire corpuscle became gradually converted into a single crystal. I have also seen a double tetrahedron result from one

* Spontaneous changes in form of Red corpuscles of Guinea-Pig's Blood, within an hour after removal from the body.

† Perfect Tetrahedral Crystals formed from Guinea-Pig's Blood. In many cases, one Corpuscle became one Crystal.

lood-corpuscle. In other instances several blood-corpuscles ran t;ether to form one large corpuscle."* (Fig. 21.)

218. The Red corpuscles, when freely floating in the 'liquor sguinis' of Blood no longer in motion, exhibit a marked tendency t approximate each other; usually coming into contact by their fttened surfaces, so that a number of them thus aggregated present the appearance of a pile of coins (*Frontispiece*, Fig. 2, *a*); (if the stratum be too thin to permit them to lie in this mnner, partially overlapping one another (as shown in Fig. 22), (even adhering by their edges, which then frequently become lygonal instead of circular. The corpuscles, when thus adherent, resist the influence of forces which tend to detach them, d will even undergo considerable changes of shape rather than sparate from each other; if forced asunder, however, they resme their normal form. After thus remaining adherent for a tie, they seem to lose their attractive force; for they are then sen to separate from each other spontaneously. This peculiar

Fig. 22.†

tdency to aggregation is most strongly manifested in inflammatry blood, and assists in that separation of the Coloured from the Colourless components in the act of coagulation which gives ie to the 'buffy coat'; whilst, on the other hand, it seems to

* See Dr. Beale 'On the Red Blood-Corpuscle,' in 'Transactions of the Microscopical Society,' Vol. xii. p. 38.

† The microscopic appearance of a drop of Blood in the Inflammatory con(ion. The *red* corpuscles lose their circular form, and adhere together; the t*te* corpuscles remain apart, and are more abundant than usual.

be neutralized by the action of most saline substances, since, if the be added to the blood, the corpuscles either do not run togeth or instantly separate if they have become adherent.—The Colou less corpuscles, on the other hand, may be readily distinguish by their complete isolation in the midst of aggregations of t Red blood-discs (Fig. 22); and this separateness may be observ even during the Circulation, for whilst the Red corpuscles mo rapidly through the centre of the capillary tube, the Colourle are seen in the exterior of the current where the motion is slo and even seem disposed to adhere to the wall of the vessel.

219. The mode in which the Red and Colourless Corpuscles a respectively generated, and their precise relations to each oth can scarcely be regarded as points yet altogether cleared up; y there are well ascertained facts which seem to throw considerab light upon these questions. In the first place, it may be stat with certainty that there is no good ground for supposing that t fully-formed Red corpuscles ever multiply themselves either b subdivision or in any other mode; and since, therefore, there evidence, if not of their *continual*, at least of their *occasional* pr duction at a rapid rate (§ 220), they must be generated by t development of germinal particles furnished by some other con ponent of the fabric. Now, in the Frog's blood, there m frequently be seen corpuscles that are pretty obviously in an inte mediate stage between the Colourless and the Red (Fig 23); the being still globular, though larger than the ord nary Colourless corpuscles, and showing in th peripheral portion a distinct layer of 'form material' which is beginning to assume the ch racteristic hue of the Red disc, but which is n tinged by the solution of carmine that deep dyes the central or nuclear portion. And the is altogether strong ground for the opinion, th in these animals the Colourless corpuscles m become converted into Red by a developmen process, which essentially consists in the production of an envelo of Hæmato-globulin as 'formed material' around the 'germin matter' that remains as the 'nucleus' of the fully-formed R corpuscle. In the case of the Mammalian blood-disc, howev the question is more difficult; on the one hand, in consequence the absence of anything like a nucleus, which leaves it doubt whether the Red corpuscle in that class is really an elementa part of the same kind as it is in the Oviparous Vertebrata; the other, from the fact that the Colourless corpuscle, instead being considerably smaller than the Red, (as in the Frog, in whi it is of about the same size as the nucleus of the Red), is not i

Fig. 23.*

* Young Red Corpuscle of Frog's Blood.

onsiderably larger. As there is very little doubt, however, that he Colourless corpuscles multiply themselves by subdivision, it oes not seem unlikely that they break up into smaller particles efore developing themselves into Red; and that in each of these *complete* conversion of 'germinal matter' into their peculiar formed material' takes place, so that none remains to constitute nucleus. And this view seems to be confirmed by the fact, that the blood of the Mammalian embryo there may be observed at very early period a great abundance of Colourless corpuscles, ving it a pale whitish hue; that these are afterwards succeeded y large nucleated Red corpuscles, in all essential respects anagous to those of Oviparous Vertebrata; and that it is only in the ter stages of embryonic development that the ordinary type of e Mammalian corpuscle becomes predominant. The Colourless rpuscles would seem to be nothing else than free-floating parcles of that general protoplasmic substance, which, as already ated, appears to form a most important constituent of the fabric en of the highest Animals. As such, they are probably conually undergoing active changes in connection with the operions of nutrition; and the increase of their own substance by e assimilation of material from the liquid in which they float, d their multiplication by subdivision, will be among the most nstant of these. It is not unlikely that they may be generated the first instance by the subdivision of those corpuscles aggreted together in the Lymphatic and (so-called) Vascular Glands, hich seem to correspond with them in their essential nature; d it has also been suggested by Dr. Beale that they may be dded off, as it were, from the nuclei of the Capillaries, in the urse of the circulation of the blood through them.

220. What is the usual term of life of the Red Corpuscles, and hether (as some suppose) there is a continual degeneration of the lest, and a corresponding supply of newly-formed discs, are quesns to which a certain answer cannot at present be given. But such variation may take place within a short time in the proportion hich these constituents bear to the whole mass of the Blood, as ows that a rapid renewal of them may occur. When much blood s been drawn from the body, the proportion of Red corpuscles in e remaining fluid is at first considerably lowered; the fluid portion the blood being replaced almost immediately, whilst the bloodcs require time for their regeneration. Their amount progressively creases, however, until it has reached its proper standard, provided at a due supply of the materials be afforded. One of these aterials is Iron; and it is well known that iron administered innally is an important aid in recovery from severe hemorrhages, as ll as a valuable remedy for certain constitutional states in which ere seems a diminished power of producing Red corpuscles. Thus i *Chlorosis*, the production of Red corpuscles is not sufficient to

make-up for the loss by death; and the total amount of them in the Blood undergoes an extraordinary diminution, sometimes even to less than a quarter of their proper proportion. Yet under the administration of iron, the amount of Red corpuscles in the blood has been doubled within a short period. In other cases, under the influence of excessive nutrition (as in the state termed *Plethora*) the proportion of Red Corpuscles is increased beyond the norma amount; and in this condition, the loss of a small quantity of blood may be a preservative from the evils to which the system is liabl from Hemorrhage of various kinds.

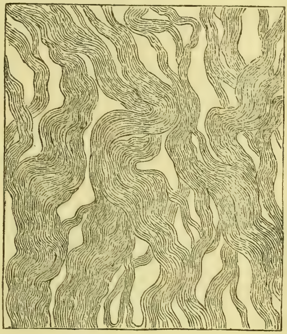
3. *Of the Simple Fibrous and Connective Tissues.*

221. A large part of the Animal fabric, especially among th higher classes in which the parts have the greatest amount motion upon one another, is composed of tissues which seem as they consisted of nothing else than *fibres* woven together in variou ways, according to the purposes they are destined to serve. The fibres are altogether different from those hereafter to be describ as constituting the Muscular and Nervous tissues, and must n be confounded with them. The former are *solid*, and possess no but *physical* properties; the latter are *tubular*, and are disti guished by their peculiar *vital* endowments, which seem chiefl if not entirely, to reside in the *contents* of the tubular fibre. Tl Simple Fibrous tissues of which we have now to treat, appear have it for their sole office in the animal body to bind-togeth the other component parts into one whole, without uniting the so closely as to render them immovable; and we find the sar elements arranged in very different modes, according to the pu poses they are destined to fulfil. Thus in the *Tendons*, by whi the muscles are connected with the bones and impart motion them, the only property required is that of resisting strain tension in *one* direction; and in these we find the fibres dispos in a parallel arrangement, passing continuously in straight li between the points of attachment. In the *Ligaments* which co nect the bones together, and which also have for their purpose afford resistance to strain, but which are liable to tension in greater variety of directions, we find bundles of fibres crossi each other according to these directions; and in some instan we find the ligaments endowed also with a certain degree of el ticity. The structure of the strong *Fibrous Membranes*, wh form the envelopes to different organs and bind together the co tained parts, is very similar; each of these membranes be composed of several layers of a dense network, formed by interweaving of bundles of fibres in different directions. In *Fibro-Cartilages*, we find a mixture of the characteristic struct of Ligament with that of Cartilage; bundles of fibres, similar those which constitute the former, being disposed among the c

which are the chief organized constituents of the latter. In certain Fibro-Cartilages, moreover, these fibres are endowed with a high degree of elasticity.

222. These two qualities,—that of resistance to tension without any yielding,—and that of resistance combined with elasticity,—are characteristic of two distinct forms of Fibrous tissue, the *White* and the *Yellow*. The *White Fibrous* tissue occurs in various forms, being sometimes composed of fibres so minute as to be scarcely distinguishable, but more generally presenting itself under the aspect of bands, usually of a flattened form and somewhat wavy in their direction, and attaining the breadth of 1-500th of an inch (Fig. 24). These bands are marked by numerous longitudinal streaks, but they cannot be torn-up into minute fibres of determinate size; hence they must be regarded as made-up of an aggregation of the same elements as those which may become developed into separate fibres. This tissue, which is perfectly inelastic, is easily distinguished from the other by the effect of Acetic acid, which swells it up, and renders it transparent, at the same time bringing into view certain oval corpuscles, which have been supposed to be the nuclei of the cells that were concerned in its formation, but of which a somewhat different account is probably to be given (§ 227).—The *Yellow Fibrous* tissue exists in the form of long, single, elastic, branched filaments, with a dark, decided border; which are disposed to curl when not put on the stretch (Fig. 25). They are for the most part between 1-5000th and 1-10,000th of an inch in diameter; but they are often met-with both larger and smaller. They frequently anastomose so as to form a network, as shown in Fig. 26; this condition especially prevails in the middle coat of the Arteries. The Yellow fibrous tissue does not undergo any change when treated with acetic acid. It exists alone (that is, without any mixture of the White) in parts which require a peculiar elasticity, such as the middle coat of the Arteries, the Chordæ Vocales, the Ligamentum Nuchæ (of Quadrupeds), and the Liga-

Fig. 24.*



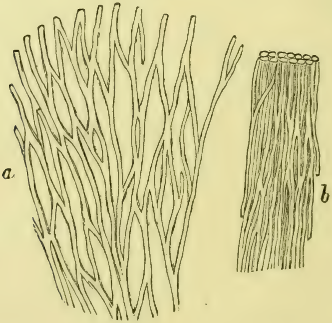
* White or Non-elastic Fibrous tissue.

menta subflava; it enters largely into the composition of certain parts which are commonly regarded as cartilaginous, such as the

Fig. 25.*

External Ear; and it is also a principal component of other tissues to be presently described.

Fig. 26.†



223. The foregoing tissues are very different in Chemical composition. Those which are composed of the *White* fibrous element—namely, Tendons, Ligaments, &c.,—are almost entirely resolved by long boiling into *Gelatin;* and this substance is also largely

* Yellow or Elastic Fibrous tissue, from ligamentum nuchæ.

† Anastomosing form of Yellow Fibrous tissue; *a*, the fibres drawn apart to show their reticulate arrangement; *b*, the fibres *in situ*.

btained from the Skin, and from Mucous and Serous membranes, ' which, as we shall presently see, that element is a principal omponent; whilst it is also yielded in great quantity by Bones, hose animal basis is almost entirely gelatinous. The *Yellow* brous tissue, on the other hand, scarcely undergoes any change y prolonged boiling; it is unaffected also by the weaker acids; id it preserves its elasticity, if kept moist, for an almost unlimited eriod. According to Scherer, it consists of 48 Carbon, 38 Hydroen, 6 Nitrogen, and 16 Oxygen; and he considers it to be comosed of an atom of Protein with two atoms of water.

224. The simple Fibrous tissues appear to be very little susceple of change in the living body; and we find them very sparingly applied with blood-vessels. In the solid Tendons, the bundles of raight parallel fibres are a little separated from each other by the itervention of the Connective tissue to be presently noticed; and is permits the sparing access of vessels to their interior. In the 'ibrous Membranes and Ligaments, this is found in somewhat rger amount; and the vascularity of these tissues is rather reater. Their great use is to afford a firm resistance to tension; y which they may either communicate motion, as in the case of *'endons;* or restrain it, as in the case of *Ligaments;* or altogether revent it, as in the case of *Aponeuroses* and *Fibrous Membranes.* Vith this firm resistance a considerable amount of elasticity may e combined, by an admixture of the Yellow fibrous tissue with he White.

225. We have now to notice a tissue in which a very different rrangement of the same elements presents itself, and the object of hich is to bind-together the elements of the different fabrics f the body, and at the same time to endow them with a greater r less degree of freedom of movement one upon another. This ssue, which is called the *Connective,* consists of a network of inute fibres and bands, which are interwoven in every direction, o as to leave innumerable *areolæ* or little spaces that communiate freely with each other. Of these fibres, some are of the Yellow r elastic kind; but the majority are composed of the White brous tissue, and, as in that form of elementary structure, they requently present the form of broad flattened bands or memranous shreds in which no distinct fibrous arrangement is visible Fig. 27). The interstices are filled during life with a fluid which esembles very dilute serum of the blood; consisting chiefly of vater, but containing a sensible quantity of common salt nd albumen. This tissue (which was once erroneously termed Cellular) is very extensible in all directions, and very elastic, rom the structural arrangement of its elements. It cannot e said to possess any distinctly *vital* endowments; for although t has a certain amount of *sensibility,* this merely depends upon he presence of nerves which it is conveying to other parts; and

the small amount of *contractility* which it shows, depends rather upon the muscular tissue of the vessels that traverse it.

226. This Connective tissue presents itself in almost every part of the body. Thus it binds together the ultimate fibres of the Muscles into minute fasciculi, unites these fasciculi into larger ones, these again into larger ones which are obvious to the eye, and these into the entire muscle. Again, it forms the membranous septa between distinct muscles, or between muscles and fibrous aponeuroses. In like manner, it unites the elements of nerves, glands, &c.; binds together the fat-cells into minute clusters, these into larger ones, and so on; and in this manner penetrates and forms a considerable part of all the softer tissues of the body. Moreover it constitutes the basis of the Skin which covers the exterior of the body, and of the Mucous, Serous, and Synovial Membranes, which line its internal cavities. But it is only to a very limited extent that it penetrates the harder organs, such as bones, teeth, cartilage, &c.; being for the most part restricted to the tracks of the blood-vessels. Its purpose obviously is, to allow a certain degree of movement between the parts it unites; and hence we find it entering much more largely into the composition of the Mammary gland (which, from its attachment to the great pectoral muscle, must have its parts capable of being shifted upon one another), than into that of the Liver, Kidneys, &c. It also serves as the *bed* in which blood-vessels, nerves, and lymphatics may be carried into the substance of the different organs; and it often undergoes a degree of condensation, in order to form a sheath for the larger trunks, which gives it almost the character of a Fibrous Membrane. — The quantity of fluid in the interstices of Connective tissue is subject to considerable variations; but these depend rather upon the state of fulness or emptiness of the vessels which traverse it, and upon the condition of the walls of those

*Fig. 27.**

* Portion of Connective tissue, showing it to be composed of bands of White fibrous tissue, and of isolated Yellow fibres.

vessels, than upon any change in the tissue itself. When an albuminous fluid is in contact with an animal membrane, the watery part of the fluid will pass through by transudation, but the albuminous matter will be for the most part kept back, so that only a very small proportion of it is to be found in the transuded liquid. When there is a want of firmness or tone in the walls of the vessels, producing (as we shall hereafter see, § 609) an increased pressure of the contained fluid on their walls, and diminished resistance, the watery part of the blood will have an unusual tendency to transudation: and we accordingly find that it then distends the areolæ, and produces *dropsy*. The physical arrangement of the parts of the tissue is so much altered, that its elasticity is impaired; and it consequently *pits* on pressure,—that is, when pressure has made an indentation in the surface, this is not immediately filled-up when the pressure is withdrawn, but a *pit* remains for some seconds or even minutes. The free communication which exists among the interstices, is shown by the influence of gravity upon the seat of the dropsical effusion; this always having the greatest tendency to manifest itself in the most depending parts, — a result, however, which is also due to the increased delay that takes place in the circulation in such parts, when the vessels are deficient in tone. This freedom of communication is still more shown, however, by the fact that either air or water may be made to pass by a continued moderate pressure into almost every part of the body containing Connective tissue, although introduced at only a single point. In this manner it is the habit of butchers to 'blow up' veal; and impostors have thus inflated the scalps and faces of their children, in order to excite commiseration. The whole body has thus been distended with air by emphysema in the lung; the air having escaped from the air-cells into the surrounding Connective tissue, and thence, by continuity of this tissue with that of the body in general at the root or apex of the lungs, into the entire fabric.

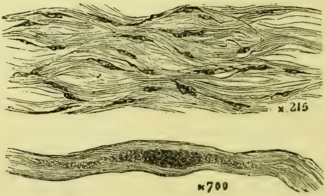
227. Very different views of the mode of development of these Fibrous tissues have been taken by those who have studied it. By some it has been maintained, that the White fibres are first developed as cells which progressively become elongated and solidified (Fig. 30), their nuclei at the same time disappearing until brought into view by acetic acid; whilst by others it has been considered that the White fibres are produced by the direct fibrillation of a *blastema* or plastic exudation (§ 188). From the analogous resistance to acetic acid shown by the Yellow fibres and the nuclei of the White, it has been supposed that the Yellow are a special product of the metamorphosis of nuclear particles, either belonging to other cells, or scattered through the blastema. For this last idea it is now pretty certain that there is no adequate foundation; and recent enquiries tend to reconcile conflicting

opinions as to the development of White fibrous tissue, by showing that the appearances on which they are respectively based may be accounted-for on one and the same interpretation. Thus if these tissues be examined in the embryo, it is found that their fibrous texture is very imperfectly marked, and that a large amount of 'germinal matter' is diffused through them, presenting itself in the condition shown in Fig. 28, that of fusiform corpuscles, interposed between the fibres, and connected with each other by radiating extensions, so as to constitute a network. From what has been already stated (§ 207), it seemed highly probable that these corpuscles are the real agents in the production of the tissue; the intervening fibrous substance standing in the relation of 'formed material' to the 'germinal substance' of which they are composed. Very similar appearances are presented by the 'false membranes' which are produced from exudations (Fig. 29); and also by the new tissue developed between the ends of a tendon which has been divided subcutaneously, so that air has no access to the wound. The 'blastema' which is poured out under these circumstances contains a large amount of

Fig. 28.*

Fig. 29.

a



'germinal matter' in the form of 'nuclear corpuscles'; and in the merely fibrinous clot which is the first product of its solidification,

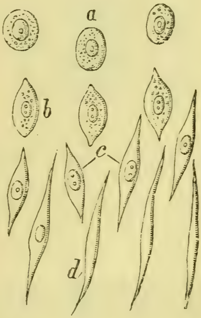
* Portion of a Tendon from the finger of a child at birth, showing the corpuscles of germinal matter, with stellate prolongations, some of which terminate in the tissue of the tendon. The preparation has been altered by teazing and pressure.

† Structure of a False Membrane; *a*, a thin section magnified 215 diameters; *b*, an elementary part magnified 700 diameters, showing the relation of the germinal matter and formed material.

would seem that there is a gradual replacement of the fibrin by at more perfect form of fibrous texture which is subsequently veloped from these. In proportion to the increase in the proper rous portion of the tissue, that is, of the 'formed material' tervening between the corpuscles of 'germinal matter,' the ter dwindle away so as to become inconspicuous; their function ing then limited to the maintenance of the integrity of the xture, which seems to undergo very little spontaneous change.*

In the production of connective tissue for the reparation of wounds which air has access, we find a mode of development which at st seems very different from the preceding, but which is yet ndamentally the same. The particles of 'germinal matter' ntained in the exudation remain completely isolated from one other, and tend to develope themselves into *cells;* approaching nearer, however, to the condition of the true cell, than do the lourless corpuscles of the Blood (§ 214). Of these corpuscles, e superficial undergo degradation, d are thrown off in the condition 'pus-corpuscles'; whilst those re deeply seated, which are protected by the layer of pus from beming deteriorated by contact with , give origin to the fibrous tissue Granulations (Fig. 30) by a pross which seems a continuation of at whose early stages have already me under our notice (§ 208),—ch corpuscle extending itself into longations which gradually take the characters of fibrous tissue.

Fig. 30†



228. From simple Connective Tise it will be convenient to pass to e *Adipose;* since isolated Fat-cells e frequently dispersed in the areolæ Connective tissue, especially beath the Skin; and where Fat occurs

It has been maintained by Virchow that these 'connective tissue-corscles' constitute a series of cells with radiating extensions, by the intermmunication of which a circulation of nutrient fluid is kept up throughout tissue. But there seems to the Author no adequate evidence of this; and accepts in preference the doctrine of Schultze, Beale, and other Histoists, who regard these corpuscles as consisting of unconverted 'sarcode' formative substance, the action of which in the diffusion of nutrient terial may be likened to that of the sarcodic network of the Rhizopods 00).

Development of Fibres from Granulation corpuscles :—*a*, circular or oval cleated corpuscles; *b*, the same becoming pointed; *c*, the same become iform, the nuclei being still apparent; *d*, the same elongating into fibres, nuclei having disappeared.

in masses, these are produced by the aggregation of similar cells bound together by Connective tissue. The cells of Adipose tissue have the power of appropriating fatty matters from the Blood, precisely in the same manner as the Secreting cells appropriate the elements of bile, milk, &c. They nearly always present a nearly spherical or spheroidal form (Fig. 31, *a*, *a*); sometimes, however, when they are closely pressed together, they become somewhat polyhedral, from the flattening of their walls against each other. A nucleus is usually discernible, attached to some part of the wall; but it cannot always be readily brought into view. When the fat-cells are dispersed through the areolæ of Connective tissue, the intervals between them are traversed by a minute net-work of blood-vessels (Fig. 32); but when they are aggregated in masses, each small cluster appears to be included in a common envelope, on the exterior of which the blood-vessels ramify; and the sacculi thus formed are held-together by Connective tissue. We are hence probably to regard each fatty mass in the light of a Gland or assemblage of secreting cells, penetrated by blood-vessels, and bound-together by fibrous tissue; but having its follicles closed instead of open (which appears to be the early condition of the follicles of *all* glands): and consequently retaining its secretion within itself, instead of pouring it forth into a channel for excretion. This secretion consists in Man of Margarin dissolved in Olein, so as to be quite fluid at the temperature of the living body (§ 176). In most other animals, the Margarin is replaced, wholly or in part, by Stearin; and this especially predominates in those fats which, becoming very solid when cold, are known as 'suet.' It seems to be by the constant moistening of the walls of

Fig. 31.*

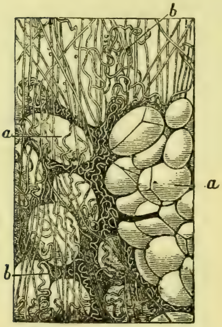
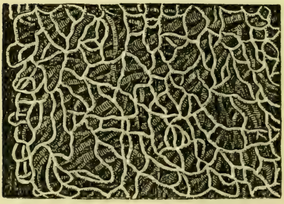


Fig. 32†



* Areolar and Adipose tissue;—*a*, *a*, fat-cells; *b*, *b*, fibres of areolar tissue.

† Capillary net-work around Fat-cells.

e Fat-cells with a *watery* fluid, that their contents are retained ithout the least transudation; for if the watery fluid of the ll-walls of a mass of Fat be allowed to dry-up, and it be kept a temperature of 100°, the escape of the contained oily matter on becomes perceptible. By this provision, the fatty matter is together prevented from escaping from the cells of the living sues through gravitation or pressure; and as it is not itself ıble to undergo change when secluded from the air, it may re-ain stored-up, apparently unaltered, for an almost unlimited riod. When, however, it is needed to supply the wants of the stem, the fatty matter is taken back into the blood; and the at-cells are then found to contain only a serous fluid. Of the ode in which this removal is accomplished, we have no certain ıowledge; but it may be surmised to be a simply physical oper-ion, related to the fact discovered by Matteucci that oleaginous ırticles in a state of fine division will pass through animal mem-anes by endosmose, to diffuse themselves through an aqueous uid on the other side, provided this be alkaline. Now the Blood ırmally contains a certain amount of fatty matter kept in sus-nsion by its excess of alkali; and should this be exhausted by e combustive process, the circulating current wlll draw into self a fresh supply from the interior of the Fat-cells.

229. The Oleaginous compounds which serve as the peculiar nstituents of Fat, are abundantly supplied by the Vegetable ngdom; and besides what they take-in as such, it seems beyond ubt that Animals have the power of generating Fatty matter by metamorphosis of starchy or saccharine substances (§ 430). here is evidence, too, that Fatty matters are produced during the trograde metamorphosis of Albuminous and other azotized com-ounds. As there is a demand for these principles wherever new ssue of any kind is being generated, (oleaginous matter being pparently an essential constituent of the *blastema* or formative aterial,) the portion separated from the circulating fluid to form dipose tissue is only that which can be spared from the other urposes to which Fatty matters have to be applied; and hence ıe production of this tissue depends in great measure on an *excess* ı the quantity of Oleaginous principles in the blood above that hich is required for the wants of the system. The development f Adipose tissue in the body appears to answer several distinct urposes. It fills-up interstices, and forms a kind of pad or cushion ır the support of movable parts; and so necessary does it seem ır this purpose, that even in cases of great emaciation some Fat always found to remain, especially at the base of the heart round the origin of the great vessels, and in the orbit of the eye. t also assists in the retention of the animal temperature by its on-conducting power; and we accordingly find a thick layer of in those warm-blooded Mammals that inhabit the seas,—either

immediately beneath their skin, or incorporated with its substance. Its most important use, however, is to serve as a reservoir of combustible matter, at the expense of which the respiration may be maintained when other materials are deficient; thus we find that the respiration of hybernating animals is kept-up, during the period when they cease taking food (§ 121), by the consumption of the store of Fat which was laid-up in their bodies previously to their passing into that state; and it is also to be noticed that herbivorous animals, whose food is scanty during the winter, usually exhibit a strong tendency to such an accumulation during the latter part of the summer, when their food is most rich and abundant, as may supply the increased demand created by the low external temperature of the winter season. Other circumstances being the same, it appears that the length of time during which a warm-blooded animal can live without food, depends upon the quantity of Fat in its body; for the rapid lowering of its temperature, which is the immediate cause of its death (§ 117), takes place as soon as the whole of this store has been exhausted.

4. *Of the Serous, Synovial, and Muco-Cutaneous Membranes, with their Appendages.*

230. The fabric of Man, in common with that of all the higher Animals, is partly composed of certain Membranous expansions of greater or less extent, which form its external investment and line its internal cavities; and which are consequently free or unattached on one of their surfaces, whilst the other is continuous with the tissues they overlie. There are three principal categories under which these membranes are capable of being grouped together; viz., the *Serous* and *Synovial* Membranes, which form shut sacs intervening between various surfaces that rub or glide one over the other; the *Mucous Membranes*, which line all the open cavities of the body; and the *Skin*, which, investing the whole exterior of the body, is continuous with the Mucous Membranes at the outlets of its open cavities. The Skin and Mucous Membranes, whilst forming one continuous system, differ greatly from each other in structural characters. The principal part of the substance of all these membranes is made up of the Simple Fibrous tissues described in the preceding Section, interwoven so as to form a sort of condensed Connective tissue, with which blood-vessels, lymphatics, non-striated muscular fibres, and nerves may be blended in varying proportions. The component fibres of the Membrane are continuous in each case with those of the looser texture which lies beneath its *attached* surface; and it has consequently no definite boundary on that side. But on its *free* surface the condensed fibrous texture is bounded by a very thin structure-

ss pellicle, termed the *basement-membrane;* which forms a limit, ot merely to its fibres, but also to its vessels, nerves, &c. This basement-membrane,' it is true, cannot always be distinguished a component of the Membranes now being described; but there strong ground for believing in the universality of its presence. is most distinctly seen as the essential component of the ultiate follicles and tubuli of the Glands which are so abundantly nnected with the Muco-Cutaneous membranes, the subjacent brous tissues not being continued to their finest ramifications.

231. Supported by this 'basement-membrane,' and covering what ould otherwise be its exposed face, we find one or more layers Cells; and these have very different endowments in different tuations, so as to impart very diversified characters to the surces they cover. Thus the *Epidermis* or 'cuticle' which overlies e *Corium* or 'true-skin' is made-up of very numerous layers of lls, of which those nearest the surface are dried and flattened to scales; and these contain a horny substance which assists in ving firmness to the pellicle, and in resisting the transudation of uid from the moist vascular surface it protects. The free surfaces the internal membranes, on the other hand, whether Serous or ucous, are covered with a cellular layer of far less consistence, rmed *Epithelium.* This term was formerly limited to what was nsidered as a prolongation of the cuticle from the lips, over the ucous membrane of the mouth, and down the œsophagus, into e stomach, where it was supposed to end. But it has been certained by means of the Microscope, that a continuous layer cells may be traced, not merely along the whole surface of the ucous membrane lining the alimentary canal, but likewise along e free surfaces of all other Mucous membranes, with their prongations into follicles and glands; as well as on Serous and ynovial membranes, and on the lining membrane of the heart, ood-vessels, and absorbents. The Epithelial cells, being always contact with fluids, do not dry-up into scales like those of the pidermis; and they differ from them also in regard to the nature the matter which they secrete in their interior. In this respect, owever, the Epithelial cells of different parts are unlike one nother, fully as much as any of them are unlike the cells of the pidermis; for we shall find that *all* the secretions of the body re the product of the elaboration of Epithelium-cells; and consequently there must be as many varieties of endowment in these imortant bodies, as there are varieties in the result of their action.

232. The *Serous Membranes* line the three great cavities of the ody, the Head, Chest, and Abdomen, together with their subdiisions; enveloping the viscera which these contain, so as to afford em an external coating over every part save that by which they re suspended; and being then reflected over the interior of the avity, so as usually to form a closed sac intervening between its

outer walls and its contents. (There is an exception in the case of the Peritoneum, which becomes continuous with the lining membrane of the Fallopian tubes, and communicates through these with the exterior of the body.) The free or unattached surface of these membranes, which is very smooth and glistening, is covered with a single layer of Epithelial cells, of flattened polygonal shape, closely fitted together like the pieces of a tesselated pavement; hence this kind of Epithelium is characterized as *tesselated* or *pavement* Epithelium. Beneath the basement-membrane on which the epithelium rests, is a layer of condensed Connective tissue, which constitutes the chief thickness of the serous membrane, and confers upon it its strength and elasticity; this gradually passes into that laxer variety by which the membrane is attached to the parts it lines, and which is commonly known as the *sub-serous* tissue. The yellow fibrous element enters largely into the composition of the membrane itself; and its filaments interlace in a beautiful net-work, which confers upon it equal elasticity in every direction. The membrane is traversed by Blood-vessels, Nerves, and Lymphatics, but usually in small proportions as compared with mucous membranes. The fluid of the Serous cavities is so nearly the same as the Serum of the blood, that the simple act of transudation is sufficient to account for its presence in their sacs; in the healthy state there is usually no more than is requisite to keep the membranous surfaces moist, and it is only in diseased conditions that any considerable accumulation takes place.—The Serous membranes do not, like the Mucous, actively participate in the performance of the Vital functions; their purpose in the economy being apparently Mechanical only. The sole end which they seem to answer is that of enclosing and suspending the Viscera, in such a manner as to allow the ready access of blood-vessels, nerves, gland-ducts, &c.; and at the same time to permit them the required freedom of motion, and to provide against the irritation of opposing parts, by furnishing an extremely smooth and moistened surface, wherever friction takes place. Notwithstanding their low degree of vitality, we find that Serous membranes, when inflamed, are peculiarly prone to throw out plastic exudations, which become organized into false membranes; and these frequently constitute 'adhesions' connecting their opposite surfaces.

233. The *Synovial* Membranes, which line the cavities of the joints, for the most part resemble Serous membranes in their arrangement and structural characters; but differ from them in certain special peculiarities. What may be considered as their original or normal disposition is shown by the dotted line in the accompanying diagram (Fig. 33), which represents the membrane as continuous over the Articular surfaces, and as reflected from them in such a manner as to form an entirely closed sac. After

e joint has come into use, however, this disposition is no longer iceable; for the components of the Synovial membrane disappear om those parts of the articular surfaces the Cartilages which are exposed to itual friction. The Synovial membanes are more copiously supplied with ood-vessels than the Serous; and these em to have special reference to the itrition of the Cartilage they cover (§ 8). In the first instance, the bloodssels are distributed over the whole rface of the cartilage; but they retreat om the rubbing surface when the joint omes into use, and at last form only a rcle around its margin, in which we id the capillary loops dilated into *amillæ* or varicose enlargements (Fig. 34). ome of the Synovial membranes, especially that of the knee-joint, are furnished with little fringe-like ojections, which are extremely vascular, and furnished with a ticker Epithelium of glandular cells, which are very easily deched. There is strong reason to believe that these are concerned

Fig. 33.*

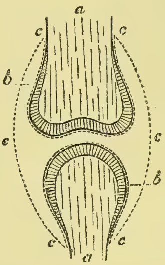
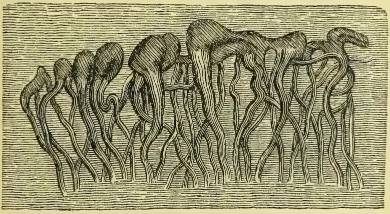


Fig. 34.*



i the secretion of the peculiar glairy Synovial fluid, which is harged with a much larger proportion of Albumen than the fluid f the Serous sacs. The *Bursæ Mucosæ* are formed of a membrane ssentially resembling the Synovial; and the fluid they contain is ynovial in its character.—These membranes are very readily egenerated after loss of substance; and they are even produced

* Ideal section of a Joint:—*a, a,* the extremities of the two articulated ones; *b, b,* the layers of cartilage which cover them; *c, c, c, c,* synovial embrane covering the articular surfaces, and passing from one to the her.

† Ampullary Dilatations of Capillary vessels between Articular Cartilage id its attached Synovial Membrane.

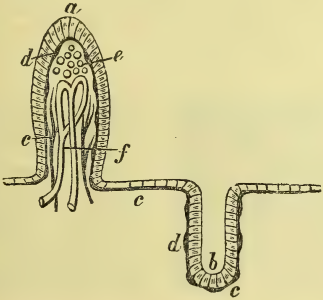
de novo when circumstances call for their existence. Thus we find regular Synovial capsules formed round the 'false joints' resulting from comminuted fractures; and new Bursæ developed between portions of the cutaneous surface exposed to much friction, and the subjacent bones.

234. The *Mucous* Membranes, like the Serous and Synovial, derive their name from the attributes of the fluid with which their free surfaces are moistened; but as this is simply protective, the term affords no indication of the peculiarities which render the system of Mucous Membranes one of the most important parts of the Animal fabric. This system includes not only the membranes which are prolonged inwards from the external surface of the body at the several orifices and outlets of its cavities, but also those extensions from the internal membranes which pass along the ducts, to ramify in the substance of the various Glands that pour their secretions into those cavities.—Thus, the *Gastro-intestinal* mucous membrane commences at the mouth, and lines the whole alimentary canal from the mouth to the anus, where it again becomes continuous with the skin; and it sends off, as branches, the membranous linings of the ducts of the salivary glands, pancreas, and liver; these membranes proceed into all the subdivisions of the ducts, and line the ultimate follicles or cæca in which they terminate. Again, the *Bronchio-pulmonary* mucous membrane commences at the nose, and passes along the air-passages, down the trachea, through the bronchi and their sub-divisions, to line the ultimate air-cells of the lungs; communicating in its course with the gastro-intestinal. Another mucous membrane of small extent commences at the puncta lachrymalia, lines the lachrymal sac and the nasal duct, and becomes continuous with the preceding. Another, which may be considered a kind of offset from either of the first two, passes-up from the pharynx along the Eustachian tube, and lines the cavity of the tympanum. Near the opposite termination of the alimentary canal, moreover, we have the *Genito-urinary* mucous membranes, which commence in the Male by a single external orifice, that of the urethra:—passing backwards along the urethra, the *genital* division is given off, to line the seminal ducts, the vesiculæ seminales, the vasa deferentia, and the secreting tubuli of the testis; another division proceeds along the ducts of the prostate gland to line its ultimate follicles, and another along the ducts of Cowper's glands:—whilst the *urinary* division lines the bladder, passes-up along the ureters to the kidney, and then becomes continuous with the membrane of the tubuli uriniferi. In the Female, the *urinary* division commences at once from the vulva; whilst the *genital* passes along the vagina into the uterus, and thence along the Fallopian tubes to their fimbriated extremities, where it becomes continuous with the serous lining of the abdominal cavity, the peritoneum.

235. Besides the Glandular prolongations here enumerated, there are many others, both from the internal and external surface. Thus we have the *Mammary* mucous membrane, commencing from the orifices of the lactiferous ducts, passing inwards to line their subdivisions, and becoming continuous with the walls of the ultimate follicles of the mammary gland. So the mucous membrane of the *Lachrymal* gland is prolonged from the conjunctival mucous membrane which covers the eye and lines the eyelids, and which is continuous with the skin at their edges.—There are numerous minute glands, again, in the substance of the Skin, and in the walls of the Alimentary canal, which need not be here enumerated; but which contribute immensely to the extension of the surface of the Mucous membrane, a prolongation of this being the essential constituent in every one. In their simplest form, these glandulæ are nothing more than little pits or depressions of the surface (Fig 35, *b*); such are found both in the Skin and Mucous membrane, and are particularly destined for the production of their protective secretions hereafter to be described.

236. Hence it is obvious that the essential character of the Mucous membranes, as regards their arrangement, is altogether different from that of the serous and synovial membranes. For whilst the latter form shut sacs, the contents of which are destined to undergo little change, the former constitute the walls of tubes or cavities in which constant change is taking-place, and which have free outward communications. Thus in the Gastro-intestinal mucous membrane, we have an inlet for the reception of the food,

Fig. 35.



* Diagram of Mucous Membrane of Jejunum;—*a*, epithelium of a villus; *b*, secreting epithelium of a follicle; *c*, *d*, basement membrane; *e*, areolæ for the reception of chyle; *f*, vessels and lacteals of villus.

and a cavity for its solution, the walls of which are endowed in a remarkable degree with absorbing power, in virtue of the outward extension of their surface into little rootlets or villi (Fig 35, *a*); whilst they are also furnished with numerous glandulæ, formed by inflections of their surface (*b*), which pour the solvent fluid into the cavity. On the other hand, it has an outlet through which the indigestible residuum is cast-forth, together with the excretions from the various glands that pour their products into the alimentary tube. In the Bronchio-pulmonary apparatus, the same outlet serves for the introduction and for the expulsion of the air; and here, too, is continual change. In other cases in which there is but a single outlet, the change is of a simpler character, consisting merely in the expulsion of the matters eliminated from the blood by the agency of the glands. Now it is, as we shall see hereafter, in the digestion and absorption of food, on the one hand, and in the rejection of effete matters on the other, that the commencement and termination of the nutrient processes consist; and these operations are entirely performed by the system of Mucous membranes.

237. Mucous membranes, although composed of the same anatomical elements as serous, have these combined in very different proportions; for whilst they have relatively less fibrous tissue, a much larger proportion of their substance is composed of blood-vessels and lymphatics. It is upon the copious supply of blood which they receive, that the reddish colour depends which they exhibit both during life and after death; and this may vary greatly in intensity according to the degree in which the vessels

Fig. 36.*

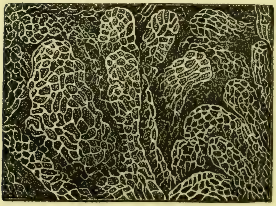
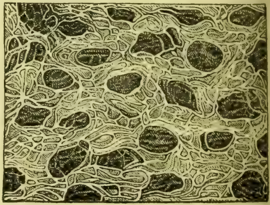


Fig. 37.†



are congested. The blood-vessels and lymphatics with which the Mucous membranes are commonly supplied, form a very minute and closely-set plexus, which spreads out beneath the basement membrane; advancing with it into the villi which it covers

* Distribution of Capillaries in the villi of the Intestine.

† Distribution of Capillaries around follicles of Mucous Membrane.

'ig. 36), and surrounding the follicles which it lines (Fig. 37). The
'ollicular' arrangement is very common in Mucous membranes;
ıe follicles being sometimes isolated from each other, and some-
mes clustered so thickly that there is only room for blood-vessels
ıd connective tissue between them. The villous arrangement,
ı the other hand, is for the most part limited to a portion of the
ıstro-intestinal mucous membrane.—The entire surface of the
ucous membranes is covered with Epithelial cells, arranged either
a single layer, or in two or more superposed layers; and this
pithelium not only lies upon the ordinary surface, but also in-
ests the villi and lines the follicles (Fig. 35); and we shall see
ıat it has a very important share in the functions of absorption
ıd secretion. A more particular description of its component
lls will be presently given.—Mucous membranes are not, for the
ost part, copiously supplied with nerves, nor do they possess
uch sensibility, except near the inlets and outlets of their cavi-
es. When diseased, they are far less disposed than serous mem-
'anes to throw out plastic exudations; but are prone to suppura-
on, ulceration, and gangrene. Their regeneration after loss of
ıbstance by disease or injury takes place with great rapidity;
ıt the tubular follicles are not always reproduced. It is inte-
sting to observe that where a portion of the Skin has been
rned inwards, so as to form the boundary of one of the internal
vities (as in plastic operations for the restoration of lips, eye-
ls, &c.), it undergoes a gradual modification in its characters,
ıd comes after a time to present the appearance of an ordinary
ucous membrane.

238. It is chiefly on the bronchio-pulmonary and gastro-intes-
ıal Mucous membranes, that we meet with the peculiar secretion
rmed *Mucus;* which appears to have for its purpose to shield
ese surfaces from the irritation they would suffer through the
ntact of air or of solids or liquids. This secretion is found also
the lining membrane of the larger excretory ducts of most of
e glands, and on that of the gall-bladder and urinary bladder;
d it is mixed in greater or less amount with the secretions dis-
arged from them, becoming very copious when the membranes
e in a state of unusual irritation. The characters of Mucus, as
tained from these different sources, are by no means constant.
general, however, it may be described as a fluid of peculiar
scidity, either colourless or slightly yellow, transparent or nearly
, incapable of mixing with water, and sinking in it except when
oyed-up by bubbles entangled in its mass, which is commonly
e case with the bronchial and nasal mucus. This fluid contains
om $4\frac{1}{2}$ to $6\frac{1}{2}$ per cent. of solid matter, of which a small part
nsists of salts resembling those of the blood, whilst the chief
ganic constituent is a substance termed Mucin, to which the
aracteristic properties of the secretion are due, and which

appears to be albuminous matter altered by the action of an alkali. When Mucus is examined with the Microscope, it is found to contain numerous epithelium-cells, together with round granular corpuscles, considerably larger than those of the blood, and closely resembling the nuclei of the epithelium-cells. These, which are known as 'mucus-corpuscles,' are particles of protoplasmic substance that seem to retain its most characteristic endowments (§ 208); and not only are they especially abundant in the more opaque mucus discharged from membranes in a state of irritation, but they present appearances of more or less advanced development into cells.

239. The Epithelium of the Mucous membranes and their prolongations is found under two principal forms, the *tesselated* and the *cylindrical*. An example of the Tesselated form is seen in Fig. 38, which shows the separate epithelium-cells of the mucous membrane of the mouth, as they are frequently met-with in saliva. The cells are not always so polygonal, however; sometimes retaining their rounded or oval form, and being separated by considerable interstices, so that they can scarcely be said to form a continuous layer. A specimen of this kind is seen in Fig. 39,

Fig. 38.*

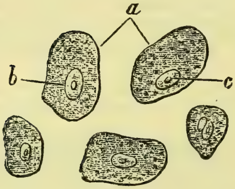


Fig. 39.†

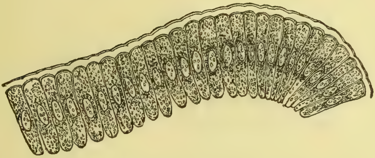
which represents a group of epithelium-cells from one of the smaller bronchial tubes. This form of tesselated epithelium is more commonly met-with where the secreting operations are more active, the life of the cells consequently shorter, and the renewal of them more frequent; so that they have not time, so to speak, to be developed into a more continuous layer.—The Cylinder-Epithelium is very differently constituted. Its component cells are cylinders which are arranged side by side (Fig. 40), one extremity of each cylinder resting upon the basement-membrane, whilst the other

* Detached Epithelium-cells, *a*, with nuclei, *b*, and nucleoli, *c*, from mucous membrane of mouth.

† Pavement-Epithelium of the Mucous Membrane of the smaller bronchial tubes; *a*, nuclei with double nucleoli.

rms part of the free surface. The perfect cylindrical form is ly shown, when the surface on which the cylinders rest is flat nearly so. When it is *convex*, the lower ends or bases of the lls are of much smaller diameter than the upper or free extremities; and thus each has the form of a truncated cone, rather

Fig. 40.*



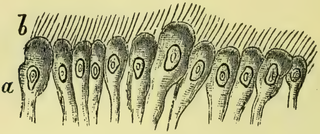
ian of a cylinder; as is well seen in the cells which cover the *lli* of the intestinal canal (Fig. 35, *a*). On the other hand, here the cylinder-epithelium lies upon a *concave* surface, the free xtremities of the cells may be smaller than those which are tached (*b*). Sometimes each cylinder is formed from more than ne cell, as is shown by the nuclei it contains; although its cavity eems to be continuous from end to end. And occasionally the ylinders arise by stalk-like prolongations, from a tesselated pithelium beneath. The two forms of Epithelium pass into one nother at various points; and various transitional forms are then een,—the tesselated scales appearing to rise more and more from ne surface, until they project as long-stalked cells, truncated ones, or cylinders.

240. Both these principal forms of Epithelial cells are frequently bserved to be fringed at their free margins with delicate filaments, hich are termed *Cilia;* and these, although of extreme minuteness, re organs of great importance in the animal economy, through the xtraordinary motor powers with which they are endowed. The orm of the ciliary filaments is usually a little flattened, and tapering gradually from the base to the point. Their size is extremely ariable; the largest that have been observed being about 1-500th f an inch in length, and the smallest about 1-13,000th. When n motion, each filament appears to bend from its root to its point, eturning again to its original state, like stalks of corn when epressed by the wind; and when a number are affected in succesion with this motion, the appearance of progressive waves following ne another is produced, as when a cornfield is agitated by frequent

* Cylinder-Epithelium from the intestinal villi of a Rabbit; *a*, *a*, pellicle onnecting their free surfaces, rendered more distinct by the action of water.

gusts. When the ciliary motion is taking place in full activity, however, nothing whatever can be distinguished save the whirl of particles in the surrounding fluid; and it is only when the rate of movement slackens, that the shape and size of the cilia, and the manner in which their stroke is made, can be clearly seen. The motion of the cilia is not only quite independent (in all the higher

Fig. 41.*



animals at least) of the will of the animal, but is also independent even of the life of the rest of the body; being seen after the death of the animal, and proceeding with perfect regularity in parts separated from the body. Thus isolated epithelium-cells have been seen to swim-about actively in water by the agency of their cilia, for some hours after they have been detached from the mucous surface of the nose; and the ciliary movement has been seen fifteen days after death in the body of a Tortoise, in which putrefaction was far advanced. In the gills of the River-Mussel, which are among the best objects for the study of it, the movement endures with similar pertinacity.

241. The purpose of this Ciliary movement is obviously to propel fluids over the surface on which it takes place; and it is consequently limited in the higher animals to the internal surfaces of the body, and always takes place in the direction of the outlets, towards which it aids in propelling the various products of secretion. The case is different, however, among animals of the lower classes, especially those inhabiting the water. Thus the external surface of the gills of Tadpoles is furnished with cilia; the continual movement of which renews the water in contact with them, and thus promotes the aeration of the blood. In the lower Mollusca, and in many Zoophytes, which pass their lives rooted to one spot, the motion of the cilia serves not merely to produce currents for respiration, but likewise to draw into the mouth the minute particles that serve as food. And in the free-moving Animalcules of various kinds, the cilia are the sole instruments which they possess, not merely for producing those currents in the water which may bring them the requisite supply of air and food, but also for propelling their own bodies through the water. This is the case, too,

* Vibratile or Ciliated Epithelium;—*a*, nucleated cells, resting on their smaller extremities; *b*, cilia.

with many larger animals of the class Acalephæ (Jelly-fish), which move through the water, sometimes with great activity, by the combined action of the vast numbers of cilia that clothe the margins of their external surfaces. In these latter cases, it would seem as if the ciliary movement were more under the control of the will of the animal, than it is where concerned only in the organic functions. In what way the will can influence it, however, it does not seem easy to say; since the ciliated epithelium cells appear to be perfectly disconnected from the surface on which they lie, and cannot, therefore, receive any direct influence from their nerves. Of the cause of the movement of the cilia themselves, no account can be given; they are usually far too small to contain even the minutest fibrillæ of muscle; and we must regard them as being, like those fibrillæ, organs *sui generis*, having their own peculiar endowment,—which is, in the higher animals at least, that of continuing in ceaseless vibration, during the whole term of the life of the cells to which they are attached. The length of time during which the ciliary movement continues after the general death of the body, is much less in the warm-blooded than in the cold-blooded animals; and in this respect it corresponds with the degree of persistence of muscular irritability, and of other vital endowments.

242. The Tesselated Epithelium, as already mentioned, covers the Serous and Synovial membranes, the lining membrane of the blood-vessels and absorbents, and the Mucous membranes with their glandular prolongations, except where the cylinder-epithelium exists. It presents itself, with some modifications presently to be noticed, in the ultimate follicles of all glands, and also in the smaller bronchial tubes. In this latter situation it is furnished with cilia; and these are also found on the cells of the tesselated epithelium which covers the delicate pia mater lining the cerebral cavities.—The Cylinder-Epithelium commences at the cardiac orifice of the stomach, and lines the whole intestinal tube; and, generally speaking, it lines the larger gland-ducts, giving place to the tesselated form in their smaller ramifications.—A similar epithelium, furnished with cilia, is found lining the air-passages and their various offsets,—the nasal cavities, frontal sinuses, maxillary antra, lachrymal ducts and sac, the posterior surface of the pendulous velum of the palate and fauces, the eustachian tubes, the larynx, trachea, and bronchi,—becoming continuous, however, in the finer divisions of the latter, with the cilated pavement-epithelium. The upper part of the vagina, the uterus, and the fallopian tubes, are also furnished with a ciliated Cylinder-Epithelium. The function of the cilia in all these cases appears to be the same; that of propelling the viscid secretions which would otherwise accumulate on these membranes, towards the exterior orifices.

243. The Epithelium-cells which are found in the interior of Glandular follicles often seem rather to occupy their cavity than merely to line their walls, and appear to be in course of continual production from the blind extremity of the follicle. This is the case alike in regard to the simple follicles or crypts of Mucous membranes, and to the ultimate follicles of the more complex Glands, which may be regarded as so many repetitions of them;—the only difference being, that the latter pour their secretion into a branch of a duct, which unites with the other ramifications to form a trunk that conveys them to their destination in some cavity lined by a mucous membrane;—whilst the simple follicles or crypts at once pour-forth their secretion upon the surface of the membrane. The accompanying figure (42) represents two follicles

Fig 42.*

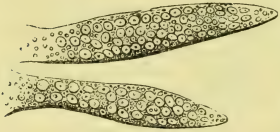
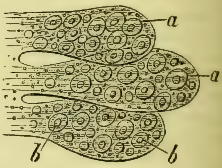
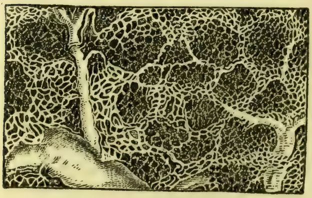


Fig. 43.†



of the liver of the common Crab, which are seen to be filled with secreting cells; it seems evident, from the comparative sizes of these cells in different parts, that they originate at the blind extremity of the follicle, and that, as they recede from that spot, they gradually increase in size, and become filled with their characteristic secretion, being at the same time pushed-onwards towards the outlet by the continual new growth of cells at the point of origin. In Fig. 43 are shown the corresponding ultimate follicles of the Mammary gland, filled, like the preceding, with secreting cells. These follicles are surrounded by a minute network of capillary vessels (Fig. 44), which is distributed in the Connective tissue that holds them together, and copiously furnishes the materials of their secretion.

Fig. 44.‡



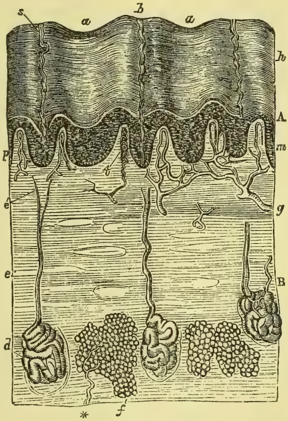
* Two follicles from the Liver of *Carcinus mœnas* (Common Crab), with their contained secreting cells.

† Ultimate follicles of Mammary gland, with their secreting cells, *a*, *a*:—*b*, *b*, the nuclei.

‡ Distribution of Capillaries around the follicles of the Parotid Gland.

244. Like the Mucous Membranes, the *Skin* may be considered made up of three components; viz. the fibrous tissue, which, ith blood-vessels, lymphatics, non-striated muscular fibre-cells, id nerves, makes up the *Cutis vera* or *Corium;* a layer of Base-ent-membrane investing this, not always capable, however, of ›ing distinctly demonstrated; and a superficial layer of peculiar iickness and tenacity, formed by the adhesion of numerous strata ' cells, which is known as the *Epidermis* or 'cuticle.'—The sub-ance of the Corium is principally composed of White fibrous ssue, which is arranged in a reticular manner, the texture being ›ry fine and close near the ırface, but more open in its ›eper layers, where its areolæ ›come occupied with clumps ' fat-cells (Fig. 45), and here it passes without any istinct line of separation into ıe subcutaneous Connective ssue. With this white fibrous ssue a small proportion of ellow or elastic fibres is usu-lly intermixed; and this pro-ortion is greatly increased in ıose parts of the skin which re subject to occasional dis-›nsion, and especially in the ıtegument surrounding the ›ints. The Cutis, in certain tuations, also contains a con-iderable number of non-stri-ted muscular fibre cells, hich are united into fasci-uli and dispersed among its ther components; these are especially abundant in the deeper part f the cutis of the scrotum, where they form the reticular layer hich is known as the 'tunica dartos'; and also in the skin f the penis and perineum, and in that of the nipple and areola. n the other parts of the integument they are especially connected ith the hair-follicles; and where these are wanting, as on the ›alms of the hands and soles of the feet, there are no muscular ibre-cells. It is by their contractility, under the influence of cold ›r of mental emotion, that the corrugation of the scrotum is pro-

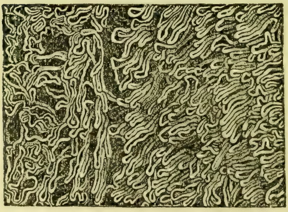
Fig. 45.*



* Vertical Section of Skin of Finger :—A, Epidermis, the surface of which hows hollow depressions, *a a*, between the papillary eminences, *b*, and the ›penings of the perspiratory ducts, *s;* at *m* is seen the deeper layer of the ›pidermis, or stratum Malpighii;—B, Cutis Vera, in which are imbedded the ›erspiratory glands, *d*, with their ducts, *e*, and also aggregations of fat-cells, *f;* t *g* is seen an arterial twig supplying the vascular papillæ, *p;* and at *t* one of he tactile papillæ with its nerve.

duced, and also that peculiar condition of the general integument which is known as 'cutis anserina,' and which is occasioned by the protrusion of the hair-follicles, whilst the intermediate cutaneous surface is retracted and depressed.—The external surface of the Corium is elevated in many parts into papillæ and ridges, which, though representing the 'villi' of Mucous Membranes, have an entirely different office. Some of them are essentially *vascular*, and seem to have for their special function to increase the surface over which the blood is distributed for the nutrition of the Epidermis. But others are essentially *nervous*, their special function being to receive tactile impressions through the medium of the nerves with which they are furnished, and their size and number being proportional to the acuteness of the sensibility possessed by the part. The latter (Fig. 45, *t*) are usually simple conical projections, each furnished with a single capillary loop, and arranged in rows so as to form ridges, with furrows between them: the former, which especially present themselves on the palm of the hand and the sole of the foot, on which surfaces the epidermis is being continually worn-off and reproduced, are commonly larger and more complex, each papilla having several distinct summits; and the ridges which they form are marked at regular intervals by short transverse furrows, into each of which the orifice of one of the sweat-glands discharges itself. It is in the papillæ that the Basement-membrane may be best distinguished as a stratum intermediate between the Corium and the Epidermis.—The surface of the Corium likewise presents numerous depressions, which are sometimes mere follicles, but sometimes tubuli of considerable length. Some of the Cutaneous follicles give origin to Hairs, in the manner to be presently described (§ 252); others, like the longer tubes (Fig. 45, *d*, *e*), are Glandular in their character, and will be described hereafter (Chap. x. Sect. 4) as part of the general excretory apparatus. The Cutis is very copiously supplied with Blood-vessels, which form capillary plexuses of great minuteness that distribute blood to the glandulæ, hair-follicles, and fat-clumps of its deeper portion, and then form a dense network near its surface, from which looped branches are sent up into the papillæ (Fig. 46). The Lymphatics of the skin, also, are very numerous, and form minute plexuses near its surface. A copious supply of Nerves, too, is sent to the skin, especially to such parts of it as are thickly set with tactile papillæ

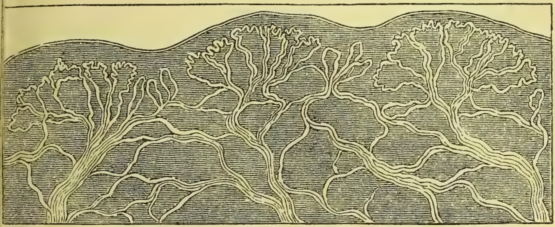
Fig. 46.*



* Distribution of Capillaries in Papillary surface of Skin of fingers.

Fig. 45, *t*); these form a minute plexus through the whole thickness of the cutis (Fig. 47), which becomes finer and closer as it approaches the surface, its branches at length coming to contain but one or two fibres each; and from the most superficial

Fig. 47.*



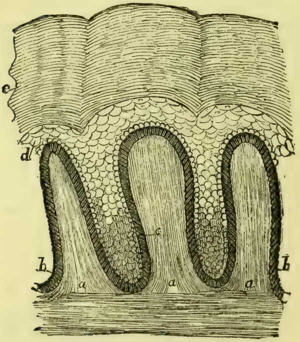
portion of the plexus fibres pass-up into the papillæ, in which they sometimes appear to form loops returning on themselves to the plexus, and sometimes seem to end by free terminations.—The regeneration of the Skin after disease or injury is effected with almost entire completeness; for not only are its fibrous and vascular components quickly reproduced, but the indications of sensibility which it presents make it evident that nerve-fibres must early extend themselves into the newly-formed substance; and tactile papillæ are reproduced upon it in appropriate situations; it is not yet certain, however, that hair-follicles and sudoriparous glands are reformed.

245. The *Epidermis* usually forms a thin semi-transparent pellicle, in close apposition with the surface of the Cutis, filling up the spaces between its papillæ, so as to obliterate its inequalities, and investing the whole with a stratum of nearly uniform thickness (Fig. 45); so that whilst its under side is pitted for the reception of the cutaneous papillæ, its outer or free surface is nearly level. In some parts, however, the Epidermis is enormously increased in thickness; such being particularly the case with those spots which are subjected to continual pressure or friction, as the palms of the hands and the soles of the feet. Its substance consists of a series of flattened scale-like cells, which, when first formed, are spheroidal, but which gradually dry up, their nuclei also at last disappearing. These form several layers, of which the deeper can be seen very distinctly to possess the cellular character, whilst the external layers are scaly; and between these, all stages of transformation may be traced,—the outer layers being conti-

* Distribution of the tactile Nerves, as seen in a thin perpendicular section of the Skin at the extremity of the human thumb.

nually thrown off by desquamation, whilst new ones are as constantly being formed below. The outer and inner portions of the Epidermis, however, present a marked difference in character, which is made still more apparent by the use of reagents; for whilst the former (Fig. 48, *e*) is a comparatively firm horny membrane, which is not affected either by acetic acid or by a moderately strong solution of potash, the latter is soft and deficient in tenacity, and is dissolved (or at least reduced to an apparently structureless condition) when treated with either of these reagents. They are further distinguished in the operation of vesicating agents; for the fluid which they cause to be effused from the vessels of the cutis, raises little else than the outer horny layer of the cuticle, passing readily through the softer tissue beneath. The internal layer of the cuticle (Fig. 48, *d*) was formerly supposed to be a distinct structure, and was termed the *rete mucosum*, or *stratum Malpighii;* it is now well known, however, to be chiefly formed by the younger portion of the Epidermis, whose cells are not yet consolidated by the formation of horny matter in their interior. In immediate contact with the basement-membrane of the cutaneous papillæ, however, there is usually found a layer of elongated cells, resembling those of columnar epithelium, arranged perpendicularly to the surface of the corium (Fig. 48, *b*, *b*); sometimes two, or even three strata of such cells present themselves. They are obviously different in character from those of the superjacent layers, for they resist the action of a solution of potash that is strong enough to dissolve the latter, though they are themselves dissolved by a stronger solution, which does not act upon the horny layer of the cuticle; and it seems not improbable that these permanently retain their place, and are not successively carried to the surface by the formation of new layers beneath, as are the spheroidal cells (Fig. 48. *c*, *d*) which lie upon them. The sphe-

Fig. 48.*

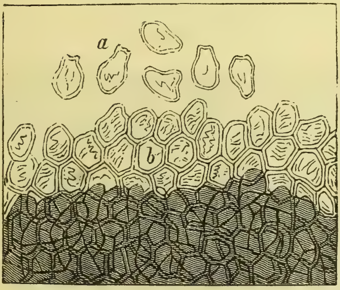


* Vertical section of the *Skin* of the Thigh of a Negro, highly magnified:— *a*, *a*, *a*, three papillæ of the Cutis; *b*, *b*, deepest layer of columnar cells, deeply coloured; *c*, spheroidal cells filling up the spaces between the papillæ, still dark; *d*, upper more faintly coloured portion of the mucous layer of the epidermis; *e*, horny layer, with scarcely any perceptible colour.

oidal cells seem to increase by duplicative subdivision before they ave acquired much consistence; and the nutriment which they equire for their growth and development must be drawn from he vessels of the Cutis through the medium of the basement-nembrane. The Epidermis is pierced by the excretory ducts of he sebaceous and sweat-glands, those of the latter passing through t with a somewhat cork-screw-like turn (Fig. 45, *s*), and both eing lined with an epithelium which is continuous with that of the nucous layer of the cuticle. It is also pierced by the Hairs, with vhose substance (as we shall presently see) it has a like relation of ontinuity through their follicles. The horny layer has the same hemical composition with Nails, Hoofs, Horns, Hair, and Wool (§ 196).

246. The Epidermis covers the whole exterior of the body, not xcepting the Cornea and the Conjunctival membrane, where, lowever, it has more the character of an Epithelium (Fig. 49);

Fig. 49.*

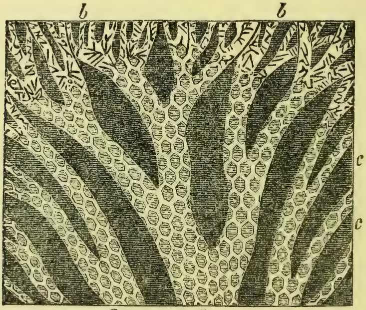


this continuity is well seen in the cast skin or *slough* of the Snake, in which the covering of the front of the eye is found to be as perfectly exuviated as that of any part of the surface. The Epidermis appears solely destined for the *protection* of the true Skin from the mechanical injury and the pain occasioned by the slightest abrasion, and from the irritating influence of exposure to air and of changes of temperature: we perceive the value of this protection, when it has been accidentally destroyed. The Cuticle is very speedily and completely replaced, however; the increased determination of blood to the Cutis, which is the consequence of the irritation, being favourable to the accelerated

* Horny Epidermis, from Conjunctiva covering the Cornea; *a*, single scales; *b*, single lamina of epithelium; below is seen a double layer of the same.

production of Epidermic cells from its surface. It is probable that pressure and friction may act in the same manner; for although the peculiar thickness of the Epidermis on the palms and soles is well marked even in the fœtus (in obvious preparation for the future requirements of these parts), yet, when parts of the surface on which the Cuticle was originally thin, are habitually exposed to pressure or friction, its substance undergoes a great augmentation. It is in this manner, that 'corns' are produced; each of these bodies being composed of an accumulation of Epidermic cells developed around a large vascular papilla.—The Cuticle is completely exuviated at the close of some Exanthematous diseases, especially Scarlatina; and we are probably to regard this as one of the modes in which morbific matter is eliminated from the system. It usually 'desquamates' in minute shreds, or peels off in larger patches; but sometimes the entire cuticle of the hand or foot, even with the nails attached, comes off at once, like a glove drawn from the hand. A new Epidermis is always pre-formed beneath that which is thus shed; as in the normal exuviation of the lower animals.

Fig. 50.*

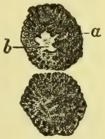


247. Mingled with the ordinary Epidermic cells, we find some which secrete Colouring-matter; these are termed *Pigment-cells.* They are not readily distinguishable in the Epidermis of the fair races of mankind, except in certain parts, such as the areola around the nipple, and in freckles, nævi, &c. But they are very

* A portion of the Choroid coat from the eye of the Ox, showing the Pigment-cells, where they cover *a*, *a*, *a*, the veins, in a single layer; *b*, *b*, ramifications of the veins near the ciliary ligament, covered with less regular pigment-cells; *c*, *c*, spaces between the vessels, more thickly covered with pigment-cells.

vious, on account of their dark hue, in the newer layers of the pidermis of the Negro and other coloured races; and, like true pidermic cells, they dry up and become flattened scales, in ssing towards the surface, thus constantly remaining dispersed rough its substance, and giving it a dark tint when it is sepated and held up to the light. The colour is more apparent in e cells of the 'stratum Malpighii,' than it is in those of the rny layer; and it is particularly deep in the stratum of comnar cells that lies in immediate contact with the surface of the itis (Fig. 48, *b*, *b*).—In all races of men, however, we find the ost remarkable development of Pigment-cells on the inner rface of the Choroid coat of the eye, where they form several yers, known as the *Pigmentum nigrum.* Here they have a very gular arrangement; which is best seen where they cover the ood-vessels of the Choroid coat in a single layer, as shown in ig. 50. When examined separately, they are found to have a lygonal form (Fig. 51, *a*), and to have a distinct nucleus (*b*) in eir interior. The black colour is given by the accumulation, ithin the cell, of a number of flat, rounded, or oval granules, easuring about 1-20,000th of an inch in ameter, and a quarter as much in thickss; these when separately viewed are obrved to be transparent, not black and paque; and they exhibit an active movement when set-free from the cell, and even hilst enclosed within it. The pigmentlls are not always of a simple rounded or lygonal form; they sometimes present rearkable stellate prolongations, under which rm they are well seen in the skin of the rog (Fig. 93, *c*, *c*).—The Chemical nature of the black pigment is not yet been made evident; it has been shown, however, to ive a close relation with that of the Cuttle-fish ink or Sepia, hich derives its colour from the pigment-cells lining the inkig; and to include a larger proportion of Carbon ($58\frac{1}{2}$ per cent.) an most other organic substances.

Fig. 51.*



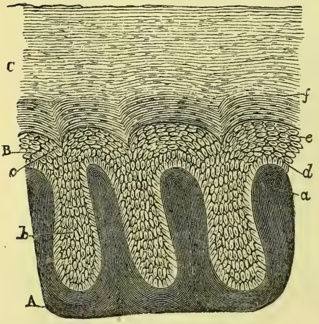
248. That the development of the Pigment-cells, or at least the rmation of their peculiar secretion, is in some degree due to the fluence of Light, seems evident from the facts already mentioned 93). To these it may be added, that the new-born infants of e Negro and other dark races do not exhibit nearly the same epth of colour in their skins, as that which they present after e lapse of a few days; which seems to indicate that exposure light is necessary for the full development of the characteristic ie. Among the inhabitants of the tropical Polynesian islands,

* Detached Pigment-cells, magnified 300 diameters;—*a*, cell; *b*, nucleus.

it is generally to be noticed that the Chiefs, who expose themselves comparatively little to the sunshine, are much fairer than the common people whose avocations are pursued in the full glare of light. An occasional development of dark pigment-cells takes place during pregnancy in some females of the fair races; thus it is very common to meet with an extremely dark and broad areola round the nipple of pregnant women; and sometimes large patches of the cutaneous surface, on the lower part of the body especially, become almost as dark as the skin of the Negro. On the other hand, individuals are occasionally seen with an entire deficiency of pigment-cells, or at least of their proper secretion, not merely in the skin, but in the eye; such are termed Albinos; and they are met-with as well among the dark, as among the fair races. The absence of colour usually shows itself in the hair; which is almost white.

249. The *Nails*, like Hoof, Horn, &c., may be regarded as nothing more than an altered form of Epidermis. When their newest and softest portions are examined, they are found to consist of nucleated cells (Fig. 52, B), resembling those of the newer layers of Epidermis; but in the more superficial laminæ (C) no distinct structure can be distinguished without the assistance of re-agents. When, however, a thin slice of the nail is immersed for some little time in a dilute solution of caustic potash or soda, its tissue swells up, and its component cells, though previously flattened and compacted together, reassume their spheroidal form, and display themselves in the most beautiful manner (as was first pointed out by Donders); their nuclei, however, are no longer distinguishable in the most superficial layers.—The Nail is produced from the surface of the Corium that lies beneath it, which is folded into a groove at its root; this surface is highly vascular,

Fig. 52.*



* Oblique section through the *Matrix of the Nail:*—A, Cutis of the bed of the nail;—B, mucous layer of the nail;—C, horny layer of the same, or true nail-substance; *a*, papillæ of the nail-matrix; *b*, cells of the Malpighian stratum of the nail; *c*, ridges of the true nail-substance; *d*, deepest layer of perpendicular cells of the mucous portion of the nail; *e*, upper layer of flattened cells of the same; *f*, nuclei of the true nail-substance.

d is furnished with longitudinal elevated ridges (*a*, *a*), to which ood-vessels are copiously distributed, and between which the ft inner layer of the nail (*b*) dips-down, like the Malpighian yer of the cuticle between the sensory papillæ. The increase the Nail in length is effected by successive additions to its root, using the whole nail to shift onwards; but as it moves it ceives additional layers from the subjacent skin, which increase s thickness. According to the observations of M. Beau, the te of growth in the nails of the hands is about 2-5ths of a line r week; whilst the nails of the feet require four weeks for the me increase. Thus, the length of the thumb-nail (including e portion hidden from sight) being 8 lines, the period occupied its growth would be twenty weeks; whilst the nail of the reat toe, in like manner, being 9 lines in length, requires ninety-x weeks, or nearly two years. It has been further remarked by I. Beau, that although the rate of growth of the nails is not uch affected by disease, the amount of nutriment they receive usually so much diminished, that the portion of nail then pro-uced is perceptibly thinner, and may be distinguished on the urface as a transverse groove. The breadth of this groove indi-ates the duration of the disease, and its depth marks the serious-ess of the disturbance of the nutritive functions; whilst its istance from the root corresponds with the length of time that as elapsed since recovery. When a Nail has been removed by iolence, or has been thrown off in consequence of the formation f pus beneath it, a complete regeneration speedily takes-place, rovided that the matrix has received no serious injury. The ail is continuous with the true Epidermis at every part, except t its free projecting edge, where also the continuity is maintained n the fœtus; so that it may be regarded as nothing else than an xtraordinary development of epidermic structure, designed to nswer certain special purposes of a purely mechanical nature.

250. The *Hair*, like the Nail, may be considered as a peculiar evelopment of the Epidermic tissue, which is produced in certain ollicles that are formed by an inversion of the Cutis; but the ubstance of which Hairs are chiefly composed (at least in Man) eparts much more widely than that of nails from the ordinary ype of Epidermic cells. Although the Hairs of different animals ary considerably in the appearances they present, we may gene-rally distinguish in them two elementary parts; a *cortical* or nvesting substance, of a fibrous horny texture; and a *medullary* or pith-like substance occupying the interior. The fullest develop-ment of both substances is to be found in the spiny hairs of the Pecari, and in the quills of the Porcupine, which are but hairs on a magnified scale; and in these we find the cortical envelope sending inwards radial prolongations, the interspaces of which are occupied by the polygonal cells of the medullary substance

(Fig. 53). The 'cortical' substance forms a dense horny tube, to which the firmness of the structure seems chiefly due; whilst the 'medullary' substance is composed of an aggregation of very large cells, which seem not to possess any fluid contents in the part of the hair that is completely formed. The structure of the feather of Birds is precisely analogous: the cortical horny tube existing alone in the quill, but being filled with a cellular medulla in the stem of the feather itself. The smaller hairs of the Sable (Fig. 54) show the cortical and medullary substances in a very characteristic form; the former being here plainly seen to be made up of flattened imbricated cells resembling those of the epidermis; whilst the cells of which the latter is composed are nearly globular. In the hair of the Musk-deer (Fig. 55), we find the medullary substance to be composed of an assemblage of cells whose walls are flattened against each other, as in a Vegetable pith; whilst the cortical envelope is scarcely distinguishable.

Fig. 53.*

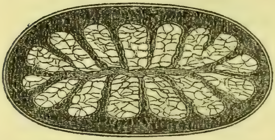


Fig. 54.†

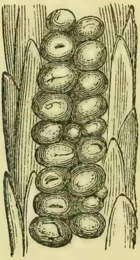
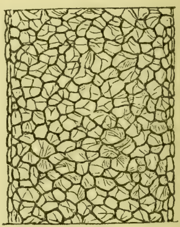


Fig. 55.‡



251. When the surface of the shaft of Human Hair is carefully examined, it is seen to be covered with a layer of flattened cells or scales, arranged in an imbricated manner, their edges forming delicate lines upon the surface of the hair, which are sometimes transverse, sometimes oblique, and sometimes apparently spiral (Fig. 56, A). Within this we find a cylinder of fibrous texture,

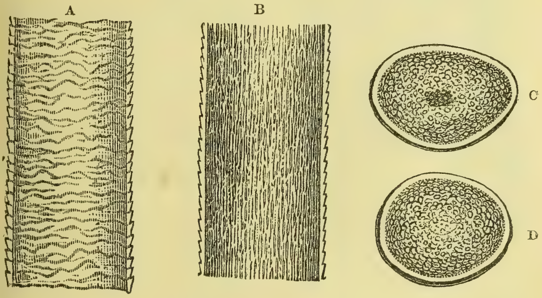
* Transverse section of Hair of Pecari.

† Hair of Sable, showing the large rounded cells in its interior, covered by imbricated scales or flattened cells.

‡ Hair of Musk-deer, consisting almost entirely of polygonal cells.

hich forms the principal part of the shaft of the hair; the con-
tituent fibres of this substance, which are marked out by delicate
ongitudinal striæ that may be traced in vertical sections of the
air (Figs. 56 B, 57, *b*), may be separated by crushing the hair,
specially after maceration in acid; and each of them consists of
fasciculus of flattened cells of a fusiform outline.—The colour
f this portion of the hair is due, not only to the presence of pig-
nentary granules, either collected into patches, or diffused through
ts substance; but also to the existence of a multitude of *lacu-
ulæ* containing air, which cause it to appear dark by transmitted
nd white by reflected light. The colouring matter seems related
o Hæmatine; it is bleached by Chlorine; and its hue appears to
e dependent in part upon the presence of iron, which is found
n larger proportion in dark than in light hair. Within the
ollow cylinder of fibrous substance, is found a canal which is
ccupied by the *medullary* portion of the hair (Fig. 56, c); this

Fig. 56.*



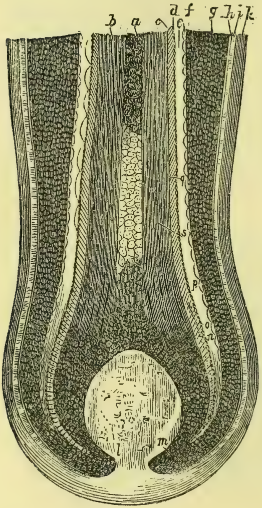
onsists of cells which retain more or less of the spheroidal shape
Fig. 57, *a*); and it generally presents a darker hue than the
ortical substance, partly through the presence of a larger
uantity of pigmentary matter in its cells, but chiefly through
he greater number of air-spaces that lie amongst them. The
nedullary substance, however, is not unfrequently wanting

* Structure of the Human Hair:—A, external surface of the shaft, showing he transverse striæ and jagged boundary caused by the imbrications of the caly layer; B, longitudinal section of the shaft, showing the fibrous character f the cortical substance, and the arrangement of the pigmentary matter; , transverse section, showing the central cord of medullary substance, disinguished by its dark hue; D, similar transverse section without the dark entre.

being usually deficient in the fine hairs scattered over the general surface of the body, and not being always present in the ordinary hairs of the head (D).

252. The real nature of the different components of the Hair, and their relation to those of the Epidermis, is ascertained by examining them at its base, and by tracing their origin and connections. The hair expands at the base of the shaft into a bulbous enlargement; and this is lodged within a follicle, formed by a depression of the Cutis, and lined by a continuation of the Epidermis. The exterior of this follicle (Fig. 57) is bounded by a fibrous membrane, derived from the Corium, whose fibres are longitudinally arranged (*k*); within this is another layer, whose fibres lie tranversely (*i*); and within this, again, is a structureless membrane, corresponding to the basement-membrane of other parts. The Epidermic lining of this follicle, which constitutes what is known as the 'root-sheath,' is composed of two principal layers, the one (*g*) in contact with the corium being the continuation of the stratum Malpighii, and the one nearest the hair (*e*, *f*) bearing a like relation to the horny layer.† At the deepest portion of the follicle, there arises a minute papillary

Fig 57.*



* Hair-bulb of a developed Human Hair, with its follicle:—*a*, medullary substance, containing air-spaces, with indistinct cells; *b*, fibrous cortical substance; *c*, *d*, inner and outer layers of the scaly envelope; *e*, *f*, inner and outer layers of the internal root-sheath; *g*, external root-sheath; *h*, structureless membrane; *i*, transverse-fibre-stratum; *k*, longitudinal fibre-stratum; *l*, hair-papilla; *m*, lowest cells of the hair-bulb, continuous with those of the external root-sheath; *n*, perpendicularly-arranged nucleated cells, which, near *q*, become non-nucleated, and are continuous with the inner layer of the scaly envelope; *o*, small perpendicularly arranged cells, likewise nucleated, passing into the outer layer of the same; *p*, lowest portion of the inner root-sheath; *r*, commencement of the medullary substance in the condition of colourless cells; *s*, part where the cells of the bulb begin visibly to lengthen themselves, to form the fusiform cells of the shaft.

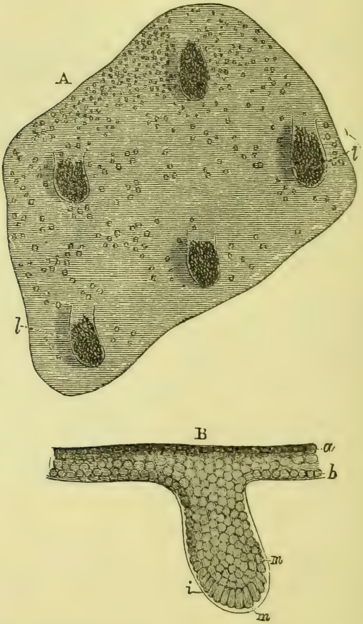
† According to Prof. Kölliker, it is by the laceration of a layer of flattened cells without nuclei, which forms the outer stratum of the inner layer of the root-sheath, that the so-called 'fenestrated membrane' is produced.

vation of the Corium (l), which occupies the centre of the hair-b; and over this we find a great accumulation of cells of eroidal form, which are obviously continuous at m with those the outer root-sheath, and are in every respect analogous hose of the Malpighian layer of the Epidermis. The envelope mbricated scales (c, d), on the other hand, which the bulb as ll as the shaft of the hair presents, commences deep in the icle as a double layer of nucleated cells (n, o), which forms a d of duplicature of the outer or horny stratum of the Cuticle. e fusiform cells of the fibrous portion of the shaft are con-uous with those of the outer part of the hair-bulb, which are n to undergo elongation (s), as they are pushed upwards by development of new cells beneath; and thus, as they are at same time narrowed, the shaft comes to be of less diameter n the bulb at its base. The cells of the medullary substance derived with less change from those of the interior of the hair-b; they are at first colourless (r), but gradually acquire the k aspect which is partly due to the development of pigmentary ter, but still more to the production of air-spaces by their ccation.

53. Thus we see that the whole tissue of the Hair is derived n Epidermic cells, developed in peculiar abundance from the face of the papilla at the base of the follicle, which is itself emely vascular; some of these cells retaining their original n, whilst others are transformed into fibres, and others con-ted (like those of ordinary Epidermis) into flattened cells. y all have the power, however, of drawing horny matter into r cavities; and resist the solvent power of chemical re-agents, ept when these are employed in unusual strength.—The Hair onstantly undergoing elongation, by the addition of new sub-ce at its base; and the part which has been once fully formed, which has emerged from the follicle, usually undergoes no sequent alteration. There is evidence, however, that it *may* ffected by changes at its base, the effect of which is propa-d along its whole extent: thus, it is well known that cases not unfrequent, in which, under the influence of strong mental tion, the whole of the hair has been turned to grey, or even silvery white, in the course of a single night; a change which scarcely be accounted for in any other way, than by supposing a fluid capable of chemically affecting the colour is secreted he base of the hair, and transmitted by imbibition through the ullary substance to the opposite extremity. Another evidence heir retention of a degree of vitality, is found in the fact of rs having a tendency to become pointed, after having been short off. In the hairs of some animals (particularly the skers of the Seal and other Carnivora) the base is hollow, and ains a large papilla, or elevation of the cutis, furnished with

nerves and blood-vessels; this is separated by a layer of basement-membrane from the proper tissue of the Hair. In such cases, there is bleeding from the stumps of the hairs, when they are shaved off close to the skin. We have seen that there is an

Fig. 58.*



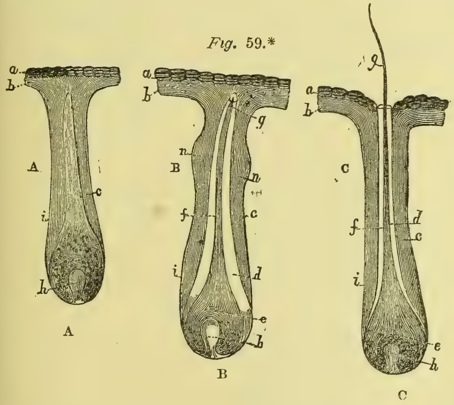
approach to this papillary structure in Man; and it may perhap be an abnormal development of it, which occasions the hair to bleed in the disease termed Plica Polonica. The hair of individuals so affected is further disposed to split into fibres, often at a considerable distance from the roots, and to exude a glutinou

* A, Development of the Hair-bulbs in the Epidermis of the forehead, in human fœtus of sixteen weeks, as seen from the under side;—B, a single hair matrix more enlarged, as seen laterally:—*a*, horny layer of the epidermis *b*, mucous layer of the same; *i*, structureless membrane surrounding the hair matrix, prolonging itself from betwixt the mucous layer and the corium *m*, rounded, with some elongated cells, forming the matrix of the hair.

ubstance; thus occasioning that peculiar *matting* of the hair, which has given origin to the name of the disease.

254. The history of the embryonic development of the Hair has been made the subject of careful study by Prof. Kölliker; and the following is the substance of his account of it. The hair-rudiments may be said to be composed of little processes of the Malpighian layer of the epidermis, which are received into corresponding depressions in the corium (Fig. 58, A, *l*, *l*); these are soon perceived to be inclosed in a limiting membrane (B, *i*), which separates the contained cells (*m*, *m*) from the interior of the follicle, just as the basement-membrane of the Skin with which it is continuous, separates the Malpighian layer of the Epidermis from the corium. The hair-matrix now lengthens and swells out at the bottom, so as to assume a flask shape. Cells are dcposited outside the limitary membrane, which are eventually converted into, or

Fig. 59.*



give place to fibres; and thus the dermic coats of the follicle are produced.—But whilst this is going on outside, the cells within the follicle undergo changes. Those in the middle lengthen out conformably with the axis of the follicle, and constitute a short conical miniature hair, faintly distinguishable by difference of

* Development of Hair in the eyebrow:—A, first distinct separation of the outer and inner portions of the hair-matrix;—B, first formation of the hair, whose point has not yet appeared above the skin;—C, the hair soon after its first emersion:—*a*, horny layer of epidermis; *b*, its mucous layer; *c*, outer root-sheath; *e*, hair-Bulb; *f*, hair-shaft; *g*, point of hair; *h*, hair-papilla; *i*, structureless membrane on exterior of matrix; *n*, commencement of sebaceous glandulæ.

shade from the surrounding mass of cells, which are also slightly elongated, but transversely with regard to the follicle (Fig. 59, A). The papilla (B, *h*) makes its appearance at the swollen root of the little hair; and the residuary cells contained within the rudimentary follicle form the root-sheath, the inner layer of which (*f*) lying next to the hair, is soon distinguished by its translucency from the more opaque outer layer (*c*) that fills up the rest of the cavity. The young hair, continuing to grow, at last perforates the epidermis (C), either directly or after first slanting up for some way between the Malpighian and the horny strata.—A shedding of the first-formed hairs, or *lanugo*, is known to take place before birth; but, according to Prof. Kölliker, only to an inconsiderable extent. On the other hand, he has observed that the infantile hairs are entirely shed and renewed within a few months after birth; those of the general surface first, and afterwards the hairs of the eyebrows and head, which he finds in process of change in infants about a year old. The new hairs are generated from the deepest portions of the original hair-bulbs, which separate themselves from the more superficial, and form separate papillæ beneath, somewhat after the manner in which the permanent tooth-sacs originate from those of the milk-teeth (Fig. 89).

5. *Of Cartilage, Bone, and Teeth.*

255. It has been usual to describe Cartilage as consisting of cells dispersed through an 'intercellular substance' or matrix: those forms of it in which the matrix is composed of the apparently homogeneous structureless material termed *Chondrin* (§ 194), being termed 'Cellular cartilages;' whilst those in which it exhibits a more or less definite fibrous arrangement are termed 'Fibro-cartilages.'—Commencing with the former, we have to enquire, in the first place, what is the precise relation of the so-called 'Cartilage-cells' to the intervening matrix; a point on which there has been considerable diversity of opinion. Some observers maintain that, at least in many forms of cartilage, the cell-wall exists as a distinct structure, the substance of the matrix being a sort of excretion from its surface, or being an independent formation directly deposited from the blood. By others, again, it has been considered that the whole intervening substance is to be regarded as constituting the common wall of the Cartilage-cells, being in fact produced by their thickening and coalescence. It is quite true that appearances are often presented by sections of Cartilage, which seem to indicate that cells provided with definite walls are lying loosely in cavities hollowed-out in a matrix; but these appearances are not presented by perfectly fresh sections of growing cartilage; being either a result of the action of water or of some re-agent upon the preparation, or being consequent upon

he shrinkage of the protoplasmic substance that originally filled he cavity, such as may often be seen to have occurred in those older parts of cartilages in which all nutritive changes seem to have ceased. And if, as Dr. Beale has shown, we carefully examine a thin section of Cartilage in course of development, we altogether fail to discern a distinct line of demarcation between the substance of matrix and the contents of its cavities; the gradation between the two being made particularly obvious when the section is soaked in carmine, which scarcely tinges the peripheral portion whilst it deeply dyes the central, staining the intervening zones less and less strongly in proportion to their distance from it (Fig. 60). Thus it appears that the true view of the nature of Cartilage is to regard it as made up of an aggregation of spheroidal segments of protoplasmic substance or 'germinal matter,' each of which has the power of becoming converted at its surface into that kind of 'formed material' which is termed Chondrin, so that these particles become separated from each other by an intervening deposit of that substance, which holds to them very much the same relation that the gelatinous substance copiously interposed between the so-called 'cells' of Sea-weeds holds to those elementary parts. In both cases it is to be borne in mind, that the intervening substance represents the cell-wall of such cells as have a distinct limitary membrane; but that the essential constituent of the cell is the segment of protoplasmic substance or 'germinal matter' which is thus isolated (§ 206). There are forms of Cartilage (Fig. 61) in which the cells are packed as closely together as those of an ordinary Vegetable parenchyma, the amount of intervening substance being comparatively small; whilst in others the cells are scattered at wide intervals, in consequence of a much larger production of 'formed material' from their surface. The first of these conditions is generally to be met with in very *young* Cartilage; whilst the second marks an advance in the development of the tissue.

Fig. 60.*

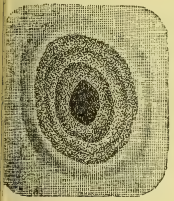
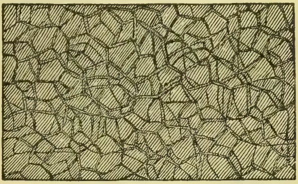


Fig. 61.*

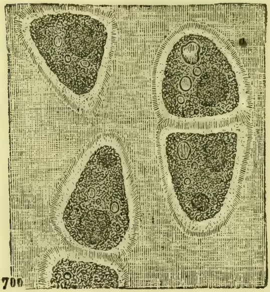


* Elementary part from Cartilage of Frog, treated with carmine, showing successive stages of conversion of germinal matter into matrix.

† Cartilage of Mouse's Ear.

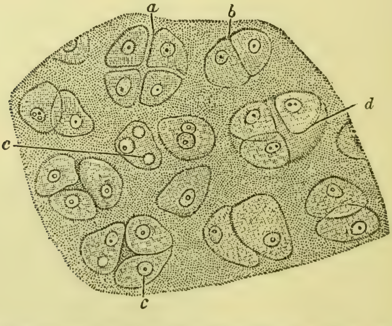
256. The growth of Cartilage results, on the one hand, from the increase in the *size* of its 'elementary parts,' each of its centres of 'germinal matter' attracting into itself fresh nutrient material from the blood, and in its turn forming an addition to the intervening matrix; but it is also due to the *multiplication* of its 'elementary parts' by the process of 'duplicative subdivision' already described (§ 212). When the mass of protoplasm has separated itself into two parts, each of these produces round itself a layer of 'formed material' (Fig. 62); and in this manner is occasioned that appearance which has given rise to the idea that the original cell-wall dips inwards to form a double partition between the two new cells formed in its cavity. Not unfrequently a second subdivision takes place before the cells of the first pair

Fig. 62.*



×700

Fig. 63.†



have been thus completely isolated from each other; and we then find clusters of four cells in the cavities of the matrix, as is shewn

* Portion of Temporary Cartilage of Frog, showing binary subdivision of its cells.

† Section of the branchial Cartilage of Tadpole:—*a*, group of four cells, separating from each other; *b*, pair of cells in apposition; *c*, *c*, nuclei of cartilage-cells; *d*, cavity containing three cells.

at *a*, Fig. 63. These groups, in the Articular Cartilages, which may be considered as the types of the purely cellular form, usually lie perpendicularly in the deeper part of the cartilage (that nearest the attached surface), and obliquely or irregularly as they approach the free surface, whilst at and near that surface they lie parallel to it. The deeper groups are composed of a larger number of cells than the superficial; and in the stratum forming the free surface, single isolated cells are not unfrequent, which have been mistaken for Epithelium-cells. The matrix of the cartilage-cells is not so perfectly homogeneous as its appearance in thin sections would seem to indicate; for when a shred of it is detached from the edge of a fractured cartilage, it is found to tear in a distinctly filamentous manner; and the arrangement of the filaments corresponds with that of the cells, being perpendicular to the attached surface of the cartilage, and parallel to its free surface, where it forms with the cells a sort of membranous layer that has been mistaken for Synovial membrane (§ 233).

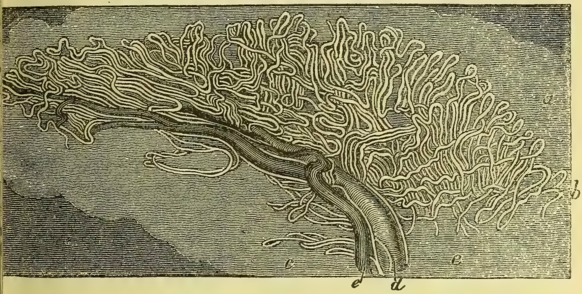
257. The varieties in the permanent Cartilages principally depend upon the degree of organization which presents itself in the 'intercellular substance.' If a mass of Fibres analogous to those of the White fibrous tissue (§ 222) should originate in it, the Cartilage presents a more or less fibrous aspect; and in some instances the Fibrous structure is developed so much at the expense of the Cells, that the latter disappear altogether, and the whole structure becomes fibrous. In this case we find that the Cartilage yields Gelatin on boiling, instead of Chondrin. Sometimes the fibres which are developed are rather analogous to those of the Elastic tissue (§ 222); these are disposed around the cells, forming a kind of network, in the areolæ of which they lie; and this kind of cartilage may be termed the 'elastic' or 'reticular.'—The primitive *cellular* organization is for the most part retained in the ordinary Articular cartilage; though these, at the points where tendons are implanted into them, have all the characters of fibro-cartilage, the fibres of the tendon spreading through the intercellular substance of the cartilage for some distance, and gradually coalescing with it. It also prevails in the cartilaginous septum narium, the cartilages of the alæ and point of the nose, the semilunar cartilage of the eyelids, the cartilages of the larynx (with the exception of the epiglottis), the cartilage of the trachea and its branches, the cartilages of the ribs (in Man), and the ensiform cartilage of the sternum; and it is seen also in the 'temporary' cartilages, or those which are destined to undergo ossification. The *fibrous* structure is seen in all those cartilages which unite the bones by synchondrosis; this is the case in the vertebral column and pelvis, the cartilages of which are destitute of corpuscles, except in and near their centres. In the lower Vertebrata, however, and in the early condition of the higher, the fibrous structure is confined to

the exterior, and the whole interior is occupied by the ordinary cartilaginous corpuscles. The *reticular* structure is best seen in the epiglottis and in the concha auris; in the former of these, scarcely any trace of cartilage-cells remains; in the latter, the fibrous net-work disappears by degrees towards the extremity of the concha, and the structure gradually passes into the cellular form.

258. Cartilage (at least in its simplest form) is nourished without coming into direct relation with the Blood through the medium of blood-vessels; for the *cellular* cartilages are not penetrated by vessels in the healthy state; and although in certain conditions they seem to become distinctly vascular, yet the vessels do not extend into the substance of the cartilage itself, but are restricted to the new tissue in which they are developed. Cartilages, however, are *surrounded* by Blood-vessels, which form large ampullæ or varicose dilatations at their edges or on their surfaces (Fig. 34); and from these the cartilages derive their nourishment by imbibition, in exactly the same manner as the frond of a sea-weed (the structure of which is alike cellular) draws into itself the requisite fluid from the surrounding medium. In the thicker masses of cartilaginous tissue, however, such as the cartilages of the ribs, we find canals excavated at wide distances from each other; which are lined by a continuation of the perichondrium or investing membrane of the cartilage, and which thus allow its vessels to come into nearer proximity with parts that would be otherwise too far removed from them. The vessels, however, do not leave the canals, which are everywhere lined by a prolongation of the investing perichondrium; and they continue to be as much *outside* the actual substance of the cartilage, as if they were distributed on its external surface alone. Similar vascular canals are found in the *temporary* cartilages, near the points at which the ossifying process is taking place; this is well seen in the long bones towards their extremities. At an early period of fœtal life, there is no distinction between the cartilage that is ultimately to become the Osseous Epiphysis, and that which is to remain as Articular Cartilage; both are alike cellular, and the vessels that supply them with nutrient materials penetrate no further than their surfaces. At a subsequent period, however, when the ossification of the epiphysal cartilage is about to commence, vessels are prolonged into it (§ 289); and a distinct line of demarcation is seen betwixt the *vascular* portion, which is to be converted into Bone, and the *non-vascular* part, which is to remain as Cartilage. If at this period, the Articular Cartilage is nourished by a plexus of vessels spread over its free surface beneath its synovial membrane (Fig. 64), as well as by the vessels with which it comes into contact at its attached extremity. Towards the period of birth, however, the sub-synovial vessels gradually recede from the surface

of the articular cartilage; and at adult age they have entirely left it, though they still form a band, the 'circulus articuli vasculosus,' which surrounds its margin. The Fibro-cartilages are somewhat vascular; but the vessels do not extend to the cellular portions, where such exist. Neither Lymphatics nor Nerves can be traced into the substance of Cartilage, which appears to be more

Fig. 64.*

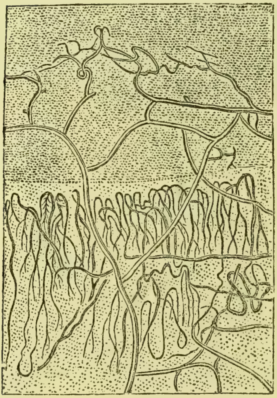


removed than almost any other tissue in the body from the general tide of nutritive action. Its properties are simply of a physical character; and they are not impaired for a long time after the death of the tissue, its tendency to decomposition being very slight, so long as it is exposed to ordinary temperatures. It is protected by its toughness and elasticity from those mechanical injuries to which softer or more brittle tissues are liable; and consequently it has little need of any active power of reparation. When loss of substance occurs as a result of disease or accident, this seems never to be repaired by real cartilaginous substance; but the space is filled-up by a fibrous tissue developed from the reparative blastema (§ 227). It is in this tissue that the new vessels are found, which have been erroneously supposed to penetrate the cartilage when it becomes inflamed; the fact being that the vessels are restricted to the 'false membrane' formed in the inflammatory process, which takes the place of the cartilaginous tissue that has disappeared in consequence of imperfect nutrition or degeneration.

* Vessels situated between the Articular Cartilage and the attached Synovial Membrane, at the point where the ligamentum teres is inserted in the head of the os femoris of the human subject, between the third and fourth months of fœtal life:—*a*, the surface of the articular cartilage; *b*, the vessels between the articular cartilage and the synovial membrane; *c*, the surface to which the ligamentum teres was attached; *d*, the vein; *e*, the artery.

259. The *Cornea* of the eye corresponds closely with Cartilage in the mode of its nutrition, and bears a superficial resemblance to it in structure; its real relation, however, being rather to the Fibrous tissues. Besides its anterior or conjunctival layer, which consists of three or four strata of epithelium-cells, and its posterior layer of cells constituting the epithelium of the aqueous humour, the Cornea proper has been shewn by Mr. Bowman to consist of three layers, which he designates respectively as the 'anterior elastic lamina,' the 'lamellated cornea,' and the 'posterior elastic lamina.'—The lamellated tissue which makes up the principal substance of the cornea, consists of superposed lamellæ, which are individually of no great extent, but are connected together both horizontally and vertically by membranous prolongations; about sixty of these lamellæ are estimated to intervene between any two corresponding spots on the opposite surfaces of the tissue; and each of them seems, when highly magnified, to present a faintly fibrous texture. The interspaces left between the superposed layers have the form of tubes, arranged with tolerable regularity, and constricted at intervals; these are more readily demonstrable, however, in the corneæ of large Quadrupeds than in that of Man. This lamellated tissue is the only part of the cornea which is continuous with the sclerotica; and its fibres appear to be very similar in every respect, save their extreme transparency, to those of that tissue.—The anterior elastic lamina is a very thin stratum of homogeneous membrane, not affected by maceration, boiling, or acids, which intervenes between the epithelial layer and the lamellated tissue; apparently serving as a 'basement-membrane' to the former, whilst it is tied down to the latter by filaments of elastic tissue, which pass from its internal surface to lose themselves among the superficial lamellæ. This layer disappears at the margin of the cornea, expending itself apparently in giving

Fig. 65.*



* Nutrient Vessels of the Cornea:—A, superficial vessels belonging to the Conjunctival membrane, and continued over the margin of the Cornea; B, vessels of the Sclerotic, returning at the margin of the Cornea.

igin to an increased number of these filaments, some of which ss into the sclerotic coat.—The posterior elastic lamina (or nembrane of Demours' or 'of Descemet') resembles the anterior the characters of its texture; but its adhesion to the posterior rface of the laminated cornea is comparatively slight, no filaents being sent down from it among the lamellæ.—No vessels n be traced into the substance of the Cornea; but its margin ke that of an articular cartilage) is surrounded by a circle of ssels, consisting of two sets, a superficial and a deep-seated 'ig. 65). The arteries of the former are derived from the Connctival membrane, and are prolonged for a short distance upon e outer layer of the cornea; but they terminate in veins at from o $\frac{1}{2}$ a line from its margin. The deep-seated vessels are derived om the Sclerotic; and they terminate in veins just where its sue becomes continuous with that of the Cornea. In diseased nditions of the Cornea (as of the articular cartilages), both sets vessels extend themselves through it; the superficial not unquently form a dark band of considerable breadth round its argin; whilst the deep-seated are prolonged into its entire subnce. Notwithstanding the absence of vessels in the healthy ndition of this structure, incised wounds commonly heal very adily, as is well seen after the operation of extraction of Catat; but the foregoing details make evident the importance of carrying the incision further round than is necessary, since corneal tissue should not be cut off from the supply of nourishnt afforded by the vessels in its immediate proximity.

260. The *Crystalline Lens* of the Eye approaches Cartilage in structure and mode of nutrition, more nearly than any other sue. The substance of which it is composed contains about 58 cent. of water; its solid constituent being that modification Albumen to which the name of *Globulin* is now given (§ 192). e lens may be separated into numerous laminæ, which are nposed of serrated fibres that lock into one another by their icately-toothed margins; these serrations, however, are much obvious on the margins of the fibres of the Human crystalline, n they are in those of the lenses of Fishes. Each fibre appears be made up of a series of cells which coalesce with each other an early period; and these are indicated, even in the fullymed fibres, by nuclei which present themselves at pretty regular ervals in their substance. A layer of unconverted cells, exnely thin and transparent, of unequal size, and nucleated, is ays found between the surface of the lens and its capsule, ich it brings into organic union. The capsule is perfectly nsparent, homogeneous, and very elastic; it forms a perfectly e envelope, admitting neither vessels nor nerves to the conned lens; but it is very readily permeable to fluids, as is shewn the absorption from the aqueous humour that sometimes takes

place after death, giving rise to the so-called 'liquor Morgagni,' the presence of which, according to Mr. Bowman, is not the normal condition. The lens itself is at no period of its existence supplied with blood-vessels, these being confined to the capsule. During the early part of fœtal life, and in inflammatory conditions subsequently, both the anterior and posterior portions of the capsule are distinctly vascular; the latter being supplied from the arteria centralis retinæ, which expands upon it after having traversed the vitreous humour, and sends branches that pass round the margin, to be distributed, with twigs from the ciliary processes, upon the anterior surface. The loops formed by the latter gradually retreat, during fœtal life, from the centre towards the margin, like those of the synovial membranes; and after a time the posterior capsule also ceases to be vascular. The subsequent growth of the crystalline lens appears to be very trifling, and appears to be sufficiently provided for by imbibition through its capsule, from the aqueous and vitreous humours which are in contact with its two surfaces respectively. Cases of the regeneration of the crystalline lens, after its complete removal by extraction, have been put upon record; but such a reparation must be extremely rare, and is probably limited to young subjects.—The *Vitreous body*, which fills the greater part of the globe of the eye, seems to be formed of a substance which resembles Connective tissue in an early stage of its formation; the proportion of its solid component being extremely small as compared with that of the fluid which fills its areolæ, and its tenacity being very slight. The fluid is little else than Water holding in solution a small quantity of albumen and saline matter. The blood-vessels which traverse the Vitreous body do not send branches into its substance; and it must derive its nutriment from those which are distributed minutely upon its general envelope, and probably also from the large plexiform vessels of the ciliary processes of the Choroid coat.

260. Before proceeding to examine the structure of *Bone*, to which it seems natural to pass-on from Cartilage, it will be useful to advert to the modes in which the tissues of Invertebrated animals are consolidated by deposits of mineral matter, in order that they may afford the requisite support and protection, without that interstitial growth which is peculiar to the skeletons of the Vertebrated classes.—As a general rule it may be stated that the lower we descend in the Animal series, the more nearly does the mode of aggregation of such mineral deposits approach that which is brought about by ordinary Crystallization (§ 2). Thus the siliceous and calcareous spicules which are dispersed through the substance of most *Sponges* and *Alcyonia*,* are obviously crystalline

* See "The Microscope and its Revelations," 3rd ed., Figs. 266, 267, 268, 279, 280.

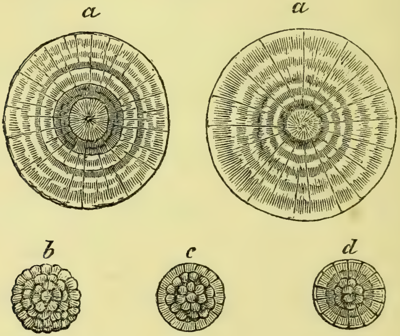
their molecular arrangement, though their forms are modified r the circumstances under which they are developed; and in me of the *Polycystina* (a tribe of Rhizopods which have a reti-lar skeleton composed of siliceous spicules, instead of being closed like *Foraminifera* in calcareous shells) the regular form well as the arrangement of the spicules distinctly marks the edominance of those forces which produce crystalline aggrega-on, over those which shape-out the living tissues. In the stony orals, again, and in the shells of Echinoderms and Mollusks, the plication of polarized light discloses the same general fact—viz., at whatever be the *form* or the *texture* of these products, the olecular aggregation of the particles of carbonate of lime is sentially crystalline, being usually the same as that of ordinary lcite, but in 'porcellanous' shells (§ 268) having the cha-cters of Arragonite. In Vertebrated animals, on the other hand, whose bones we find the Carbonate of Lime for the most part perseded by the Phosphate, this last salt appears to enter into timate combination with the gelatigenous substance which con-tutes the animal basis of Bone (§ 194); and we here seem to lose l trace of crystalline aggregation. There is, however, an inter-ediate set of cases, in which Carbonate of Lime deposited in the idst of Organic matter forms itself into aggregations which are ot properly crystalline, yet have much of the crystalline cha-cter; and the conditions under which these are produced have en experimentally investigated by Mr. Rainey, who has opened an enquiry likely to yield a rich harvest of valuable results to y one who may pursue it with due care and sagacity.*

262. Mr. Rainey's method of experimenting essentially consists bringing-about a slow decomposition of the salts of lime con-ined in gum-arabic, by the agency of subcarbonate of potash. ne result is the formation of spheroidal concretions of Carbonate Lime, which progressively increase in diameter at the expense an amorphous deposit which at first intervenes between them; o such spherules sometimes coalescing to produce 'dumb-bells,' hilst the coalescence of a larger number gives rise to the mul-rry-like body shown in Fig. 66, *b*. The particles of such mposite spherules appear subsequently to undergo re-arrange-ent according to a definite plan, of which the stages are shown *c* and *d*; and it is upon this plan that the further increase kes-place, by which such larger concretions as are shown at *a*, *a*, e gradually produced. The structure of these, especially when amined by polarized light, is found to correspond very closely

* See his treatise "On the Mode of Formation of the Shells of Animals, of ne, and of several other Structures, by a process of Molecular Coalescence, nonstrable in certain artificially formed products" (1858); and his "Fur-r Experiments and Observations" in "Quart. Journ. of Microsc. Science," S., vol. i. (1861), p. 23.

with that of the small calculous concretions which are common in the Urine of the Horse, and which were at one time supposed to have a matrix of cellular structure. The component particles of the small calcareous concretions termed 'otoliths,' or ear-stones, found in the auditory sacs of Fishes, present an arrangement essentially the same. Similar concretionary spheroids occur in the skin of the Shrimp and other imperfectly-calcified shells of Crustacea (§ 272); they occur also in certain imperfect layers of the shells of Mollusca; and we have a very good example of them in the outer layer of the envelope of what is commonly known as a 'soft egg,' or an 'egg without shell,' the calcareous deposit in the

Fig. 66.*



fibrous matting already described (§ 188) being here insufficient to solidify it. In the external layer of an ordinary egg-shell, on the other hand, the concretions have enlarged themselves by the progressive accretion of calcareous particles, so as to form a continuous layer, which consists of a series of polygonal plates resembling those of a tesselated pavement. In the solid 'shells' of the eggs of the Ostrich and Cassowary, this concretionary layer is of considerable thickness; and vertical as well as horizontal sections of it are very interesting objects, showing also beautiful effects of colour under polarized light.—From the researches of Prof. Williamson on the Scales of Fishes, there can be no doubt that much of the calcareous matter which they contain is deposited upon the same plan; and it is probable that by a further study of the relations between their structure and that of true Bones and Teeth, the principle of 'molecular coalescence' will be found in

* Artificial Concretions of Carbonate of Lime.

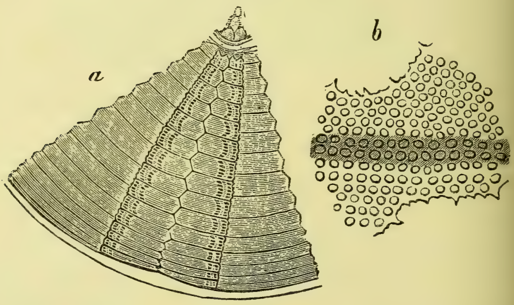
me degree applicable to the explanation of the special pecu-
ırities of the latter.

263. Commencing with the *Polypifera*, or Coral-forming ani-
als, we observe that their stony axes or sheaths are destined
ıly to give *support* to their softer structures, and that the parts
ıce consolidated undergo no subsequent interstitial change. It
as formerly imagined that the stony Corals were 'built-up' by
e animals which form them, somewhat in the same manner as a
ee constructs its cell. But it is now fully demonstrated that
e calcareous matter (which here consists solely of the *Carbonate*
Lime) is deposited in the living tissue, and that the most solid
ass of Coral thus has an organic basis. That basis, however,
ppears to be a structureless sarcode, in which no differentiation
parts has taken place; and the proportion it bears to the earthy
posit is so small, that very little if any nutrient change can
ke place in these structures when once consolidated. Such
ıanges are not, however, required. The substance thus developed
the attractive power of the soft gelatinous tissues, which draw
to themselves the small quantity of calcareous matter dissolved
the surrounding water, is so little disposed to undergo change,
at it will maintain its solidity for centuries; and even when
ted-on by water or by heat, it does not undergo disintegration,
r its calcareous particles arrange themselves in a new method,
ıd become converted into a solid crystalline rock. Such rocks,
e product of the metamorphosis of ancient Coral-formations,
ake-up a large proportion of the external crust of the earth.
ıe solid stem or sheath, once consolidated, appears to undergo
further change in the living Coral-structure; for its increase
kes place not by *interstitial* but by *superficial* deposit, that is,
t by the diffusion of new matter through its whole substance,
parating from each other the parts formerly deposited, but by
e mere addition of particles to its surface and extremities. In
is manner, the growth of a solid Coral-structure may proceed
an enormous extent; the surface at which the consolidating
tion is going-on being the only part *alive*, that is, exhibiting
y vital change; and all the rest of the mass being henceforth
rfectly inert. Still there is evidence that the *removal* of parts
ce consolidated may be effected by an action of living tissues
their *surface*.

264. In the class of *Echinodermata*, which includes the Star-
h, Sea-Urchin, &c., we find the calcareous skeleton presenting
very elaborate organization; as an example of this, we shall
ect the shell of the *Echinus*, commonly known as the 'sea-egg.'
ıis shell is made-up of a number of plates, more or less regu-
ly hexagonal, and fitted together so as completely to enclose
animal, except at two points, one of which is left open for the
outh, the other for the anus. On the surface of these plates are

little tubercles for the articulation of the 'spines,' which serve as instruments of defence and of locomotion. The substance of the shell and of the spines is exactly alike; being a sort of calcareous reticulation having an innumerable series of areolæ or interspaces freely communicating with each other. The arrangement of this calcareous net-work in the spines is most varied and elaborate; and causes thin sections of them to be among the most beautiful of all microscopic objects.* The matrix in which this net-work is deposited appears (from the Author's recent observations) to be nothing else than a sarcodic substance, in which the granules are collected into little aggregations that occupy the areolæ of the reticulation, whilst the calcareous deposit takes place in the intervening homogeneous material. A portion of unconsolidated substance intervenes between the adjacent plates; and the entire shell is covered with a membrane that seems to consist of the same substance in a state of greater condensation. A similar membrane invests the spines, and is continuous at their bases

Fig. 67†.



with that which covers the shell; a distinct fibrous arrangement being discernible at the line of junction, whereby the motion of the spines is provided for.

265. But we do not here find any evidence of *interstitial growth*, nor is there any reason why such should be required. For the tissue of which it is composed, although of such extreme delicacy is of great permanence, and does not exhibit the slightest tendency to decay, however long it is preserved; so that when once conso-

* See the Author's Manual entitled "The Microscope and its Revelations," Chap. xii.

† Portion of the shell of the Echinus; showing at *a* the constituent plates and at *b* the calcified network of which they are composed

lated, it appears to undergo no further change in the living uimal. The growth of the animal, however, requires a corre- onding enlargement of its enveloping shell; and this is provided r by the simple process of superficial deposit, through the sub- vision of the whole shell into component plates. For the dition of new matter *at the edge of each plate*, by the consolid- ion of a portion of the soft tissue that intervenes between the jacent plates, enlarges the whole shell without altering its obular form; whilst the consolidation of the soft tissue at the *rface* of each plate at the same time strengthens it in a cor- sponding degree. In like manner, the spines are enlarged d lengthened by the progressive formation of new layers, each the exterior of the preceding, so that their transverse section hibits a number of concentric rings like those of an Exogenous em. In no part of the matrix of the shell do we find the least ice of vessels; the nutrient material being entirely brought by e sarcodic substance that is continuously distributed throughout. ius even in the growth of this complex and elaborate structure, e recognize the principle of *superficial deposit*, which we shall d to be universal amongst the hard parts of the Invertebrata: twithstanding that, at first sight, it would have appeared im- ssible to provide on this plan for the gradual enlargement of a obular shell, completely enclosing the animal, and therefore quired to keep pace with the latter in its rate of increase.—But hough modifications of form, as well as augmentations of size, are is effected by the *additions* made to the component pieces of the eleton, a careful study of the developmental history of certain these animals leaves no doubt in the mind of the Author that a *moval* of certain parts must also take place; this removal, how- er, being effected by an action on the surface alone, and not rolving any such interior modification as we shall find to take ce in Bone (§ 293).

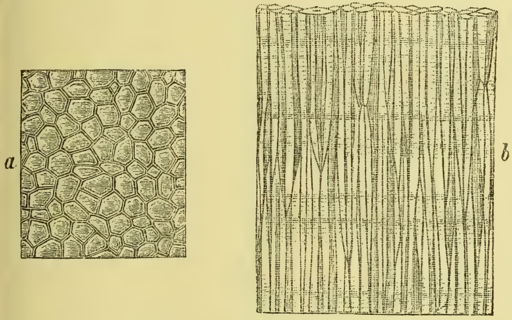
266. Among the Mollusca, we find the body sometimes altogether stitute of solid organs of support, protection, or locomotion,—as the case, for example, in the Slug: and the movements are ble and the habits inert, the muscles having no fixed points for ir attachment, and acting without any of the advantages of erage. In other cases, we find the body more or less com- tely protected by a Shell; which is sufficiently large in some tances to cover the body completely, whilst in others it affords y a partial investment. The plan on which this shell is formed, wever, is very different from that which has just been described; ng much less complex. The *Univalve* shells, or those formed one piece, are always of a conical form; the cone being some- ies simple, as in the Limpet; in other cases being spirally led, as in the Snail. Now the base of this cone is open; and ough this, the animal can project its movable parts. When

the increasing size of its body requires additional accommodation, an addition to the large end of the cone increases its diameter and its length at the same time; so as to afford the required space, without any alteration in the form or dimensions of the older and smaller portions of the cone. This last, indeed, is frequently quitted by the animal, and remains empty; being sometimes separated from the later portions by one or more partitions thrown-across by the animal,—as is seen especially in the Nautilus and other 'chambered' shells. Besides the new matter added to the mouth of the shell, a thin layer is usually formed over its whole interior surface; so that the lining of the new part is continuous with that of the old.—In the *Bivalve* shells which usually cover the upper and lower surfaces of the animal they protect, we trace this mode of increase without any difficulty; especially in such shells as that of the Oyster, in which the successive laminæ remain distinct. Each lamina is *interior* to the preceding, being formed on the living surface of the animal; but it also projects beyond it, so as to enlarge the capacity of the shell; and as the separation of the valves affords free exit to those parts of the animal which are capable of being projected beyond the shell, there is obviously no need of any other provision to maintain the shell in its natural form.—Thus, in the shells of the Mollusca, increase takes place at the surfaces and edges only.

267. The proportions of the Organic and the Mineral components of Shell differ considerably in the various tribes. The former is sometimes present in such small amount that it can scarcely be detected; and the condition of the calcareous matter then obviously approaches that of a crystalline deposit. But in other instances the animal basis is very obvious; remaining as a thick consistent membrane, after all the calcareous matter has been dissolved-away by an acid. This is particularly well seen in the outer layer of the shell of *Pinna;* in which the carbonate of lime is deposited in elongated prisms that stand side by side like basaltic columns (Fig. 68, *b*), but are separated by the intervention of laminæ of animal matter, the cross section of which (*a*) so closely resembles that of a vegetable cellular parenchyma, as to suggest the idea that the prisms are deposited in the cavities of elongated prismatic cells. Such was, in fact, the idea generally formed of this structure when its microscopic characters were first brought into view; the long prismatic cells being supposed to be formed by the coalescence of epidermic cells in continuous piles, this coalescence being marked by the transverse striæ seen on the prisms. The progress of enquiry, however, has led to an important modification of this interpretation; the Author being now disposed to agree with Prof. Huxley in the belief that the entire thickness of the shell is formed as an *excretion* from the surface of the integument of the animal; and that the horny layer which

ı ordinary shells is found as an external envelope or 'periosacum' (often but erroneously called the 'epidermis' of the shell), eing here thrown out at the same time with the calcifying mateal, is converted into the likeness of a cellular membrane by the ressure of the prisms that are formed by crystallization at regular stances in the midst of it.—This *prismatic* shell-structure is of pecial interest from its obvious relation to the Enamel of Teeth 305). In most other Bivalve shells there is but little evidence any definite structural arrangement; and the proportion borne y the animal basis to the calcareous deposit is very small. In me instances the carbonate of lime is deposited in nodules that rongly resemble those artificially produced (§ 262).

Fig. 68.*



268. A similar predominance of the mineral over the organic nstituent prevails throughout the 'Univalve' shells of the class *asteropoda;* the residuum left after the removal of the calcareous atter being usually so imperfect, as to give no clue whatever to e explanation of the appearances shewn by sections. Neverthess, the structure of these Shells is by no means homogeneous, but ways exhibits indications, more or less clear, of an original ornic arrangement. The 'porcellanous' shells are composed of ree layers, all presenting the same kind of structure, but each ffering from the others in the mode in which this is disposed. or each layer is made-up of an assemblage of thin laminæ placed de by side, which separate one from another, apparently in the anes of *rhomboidal* cleavage, when the shell is fractured; and

* Prismatic cellular structure of shell of Pinna:—*a*, surface of lamina; vertical section.

each of these laminæ consists of a series of elongated spicules lying side-by-side in close apposition; and these series are disposed alternately in contrary directions, so as to intersect each other nearly at right angles, though still lying in parallel planes. The direction of the planes is different, however, in the three layers of the shell, bearing the same relation to each other as have those three sides of a cube which meet each other at the same angle; and by this arrangement, which is better seen in the fractured edge of *Cypræa* or any similar shell than in thin sections, the strength of the shell is greatly augmented. A similar arrangement, obviously adapted to the same purpose, has been shewn by Mr. Tomes to exist in the enamel of the Teeth of Rodentia. —Of the so-called 'naked' Gasteropods, there are many, both terrestrial and marine, which have some rudiment of a shell. Thus, in the common Slug, *Limax rufus*, a thin oval plate of calcareous texture is found imbedded in the shield-like fold of the mantle covering the fore-part of its back; and if this be examined in an early stage of its growth, it is found to consist of an aggregation of minute calcareous nodules, generally somewhat hexagonal in form, and sometimes quite transparent, in other instances presenting an appearance of radiating crystallization. In the epidermis of the mantle of some species of *Doris*, on the other hand, we find long calcareous spicules, generally lying in parallel directions, but not in contact with each other, giving firmness to the whole of its dorsal portion; and these are sometimes covered with small tubercles. They may be separated from the soft tissue in which they are imbedded, by means of caustic potash; and when treated with dilute acid, whereby the calcareous matter is dissolved-away, an organic basis is left, retaining in some degree the form of the original spicule. This basis cannot be said to be a true cell; but it seems to be rather a cell in the earliest stage of its formation, being an isolated particle of 'sarcode' without wall or cavity; and the close correspondence between the appearance presented by thin sections of various 'univalve' shells, and the forms of the spicules of Doris, seems to justify the conclusion that even the most compact shells of this group are constructed out of the like elements in a state of closer aggregation and more definite arrangement, with the occasional occurrence of a layer of more spheroidal bodies of the same kind, like those forming the rudimentary shell of *Limax*.

269. The *permanent* character of the substance of all Shells, when once it is fully formed, is as remarkable as that of Coral; and as the adaptation of their size to that of the animals to which they belong, is entirely effected by additions to their surfaces and edges, no interstitial deposit can have a share in producing it. There are numerous instances among Mollusca, however, of the *removal* of parts of the shell whose continued presence would be

convenient; the best examples of this modification being found among the Spiral Univalves. Thus we often find that the ridges, os, or processes, into which the surfaces of the shells of *Murex*, *riton*, &c., have been extended, are removed to make way for e succeeding turn of the spire. In other cases, again, we find e partitions between the interior whorls more or less completely moved with the advance of life. And there is a land-snail (benging to the genus *Bulimus*) which always loses the apical poron of its shell when it attains adult age; this being separated by e thinning away of the part below, and a partition being thrown ross the 'decollation.' In all these cases, the action is entirely *perficial*, and appears to be of the same nature as that by which e Limpet excavates a hollow in the rock to which it adheres, or y which the *Pileopsis* makes a like excavation on the surface of e shell to which it attaches itself.

270. Among the *Articulated* classes, we still find that the sketon is altogether external; but it is formed upon a very different lan from the shells of the Mollusca, being closely fitted to the ody, and enveloping every part of it; consequently it must inease in capacity in accordance with the growth of the contained ructures. Moreover it is destined not merely to afford support nd protection to these, but to serve for the attachment of the uscles by which the body and limbs are moved; and the hard nvelopes of the latter serve, like the bones of the Vertebrata, as vers by which the motor powers of the muscles are more advangeously employed. Again, the hard envelopes of the body and mbs are not formed of distinct plates, like those of the Echinus hell; but are only divided by sutures at the joints, for the purose of permitting the requisite freedom of motion. It might have een thought that here, if anywhere, a process of interstitial rowth would have existed, to adapt the capacity of the envelopes o the dimensions of the contained parts, as the latter increase vith the growth of the animal; but this requirement is provided or in Articulated animals by the throwing-off or exuviation of he hard envelopes, when the contained parts require an increase f room; a new covering being formed from their surface, adapted o their enlarged dimensions.

271. This is well known to occur at certain intervals in Crabs, obsters, and other *Crustacea;* which thus exuviate not merely he outer shell, with its continuation over the eyes, but also its nternal reflexion which forms a lining to the œsophagus and tomach, with the tendinous plates by which the muscles are atached to the lining of the shell. A similar moulting may be bserved to occur in some of the minute Entomostracous Crusacea of our pools, every two or three days, even after the animals eem to be full grown. During the early growth of Insects, Spiders, Centipedes, &c., a similar moult is frequently repeated at

short intervals; but after these animals have attained their full growth, which is the case with Insects at their last change, no further moulting takes place, the necessity for it having ceased. This moulting is analogous to the exfoliation and new formation of the Epidermis in Man and most other Vertebrata; differing from it only in this, that the latter is constantly taking place to a small extent, whilst the former is completely effected at certain intervals, and then ceases. We have examples of a periodical complete moult in Vertebrata, however, among Serpents and Frogs.

272. The substance termed *Chitin*, of which the horny casing of *Insects* is composed, differs considerably in composition from the material of the Epidermic tissues of higher animals (§ 196), its formula being $C^{17} H^{14} NO^{11}$; and there are reasons for considering it as more allied to Cellulose (notwithstanding that it includes Nitrogen) than to the Albuminous compounds and their derivatives. It is insoluble in water, acetic acid, and alkalies; but dissolves with decomposition in the strong mineral acids.—Notwithstanding the appearances of definite cellular structure which this casing often presents, there is reason to believe that it is really (like the shells of Mollusca) an exudation from the surface of the proper integument of these animals; resembling in this respect the delicate pellicle that overlies the cellular cuticle of the leaves of Plants. In the larger Decapod *Crustacea*, such as the common Crab, we find beneath the structureless horny envelope a layer of a calcified substance, which is found on minute investigation to be as minutely tubular as dentine (§ 302); the tubuli running from the inner to the outer surface, without either branching or altering in size. This structure is particularly well seen in the black extremity of the claw, which is much denser than the rest of the shell, having almost the hardness and semi-transparence of ivory. The solidifying material consists chiefly of carbonate of lime; but traces of the phosphate are also found. In some of the smaller Crustacea, as the common Shrimp, the calcareous matter is disposed in the form of concentric spherules, which correspond closely with those which may be artificially produced by 'molecular coalescence' (§ 262).

273. Now the condition of the Osseous Skeleton of *Vertebrated* animals is altogether different. Its purpose is still only mechanical; its sole use being to afford support and protection to the softer textures, and to supply a set of inflexible levers, by the action of the muscles upon which, motion may be given to the different parts of the fabric. But it forms a part of the internal substance of their bodies; and as these grown in *every* part, and not merely by addition to this or that portion, so must the Bones also, in order to keep pace with the rest of the structure. Hence we find them so constructed that the processes of *interstitial*

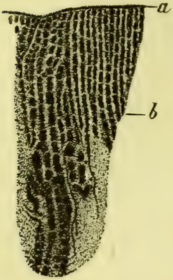
deposition may be continually going-on in their fabric, as in that of the softer tissues; and the changes in their substance do not cease, even when they have acquired their full size. The subsequent continuance of these changes appears destined not so much to repair any *waste* occasioned by decomposition,—for this must be very trifling in a tissue of such solidity,—as to keep the fabric in a condition in which it may repair the injuries in its substance occasioned by accident or disease. The degree of this reparative power is proportional, as we shall presently see, to the activity of the normal changes which are continually taking place in the bone; and is thus much greater in youth than in middle life, and greater in the vigour of manhood than in old age.

274. The structure of Bones is well adapted to demonstrate the distinction between the tissues themselves, and those subsidiary parts by which they are connected with the rest of the fabric. We have seen that Cartilage is essentially *non-vascular;* that is, it is not traversed by vessels, even when it exists in a considerable mass, but is nourished by absorption from the fluids contained in the vessels distributed on its exterior. Now every mass of Bone is traversed by vessels; nevertheless these do not penetrate its ultimate substance, and may be easily separated from it, leaving the bone itself as it was. In fact, as Prof. Goodsir observes, "a well macerated Bone is one of the most easily made, and, at the same time, one of the most curious of anatomical preparations. It is a perfect example of a texture completely isolated; the vessels, nerves, membranes, and fat are all separated, and nothing is left but the non-vascular osseous substance." Precisely the same may be said of the substance of a Tooth from which the vascular lining of the pulp-cavity has been removed; for it then possesses neither vessels, nerves, nor lymphatics; and yet, as we shall presently see, it has a highly-organized structure peculiar to itself.

275. The general characters of Osseous texture vary according to the shape of the Bone, and the part of it examined. Thus in the *long* bones, we find the shaft pierced by a central canal, which runs continuously from one extremity to the other; and the hollow cylinder which surrounds this, is very compact in its structure. On the other hand, the dilated ends of the bone are not penetrated by the large central canal; nor are they composed of solid osseous substance. They are made-up of *cancellated* structure, as it is termed; that is, of osseous lamellæ and fibres interwoven together (like those of connective tissue, on a larger scale) so as to form a multitude of minute chambers or *cancelli* (Fig. 69), freely communicating with each other and with the cavity of the shaft; whilst the whole is capped with a thin layer of solid bone. Again, in the thin flat bones, as the scapula, we find the two surfaces composed of solid osseous texture, with more or less of

cancellated structure interposed between the layers. And in the thicker flat bones, as the parietal, frontal, &c., this cancellated structure becomes very distinct, and forms the diploë; this, however, is sometimes deficient, leaving a cavity analogous to the canal of the long bones: whilst the plates which form the surfaces of the bone (the external and internal table of the skull) resemble in their thickness and solidity, as well as in the intimate structure presently to be described, the shaft or hollow cylinder of those bones. Finally, we frequently meet (especially in the Ethmoid and Sphenoid bones of Man, and in the Scapula of a Mouse or other small Mammal) with thin lamellæ of osseous substance, resembling those which elsewhere form the boundaries of the cancelli; these consist of but one layer of osseous substance, and show none of the varieties previously adverted-to; they are not penetrated by vessels, but are nourished only by their surfaces; and they consequently exhibit to us the elements of the osseous structure in their simplest form. It will be desirable, therefore, to commence with the description of these.

Fig. 69.*

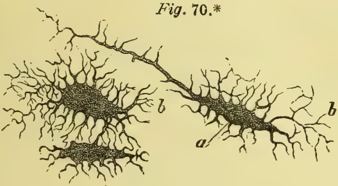


276. When a thin natural lamella of this kind is examined, it is found to be chiefly made-up of a substance which is nearly homogeneous, sometimes exhibiting indistinct traces of a fibrous arrangement; this, however, may be generally resolved by prolonged boiling into an assemblage of minute granules, varying in size from 1-6000th to 1-14,000th of an inch, which are more or less angular in shape, and seem to cohere by the medium of some second substance which is dissolved by the boiling. They are composed of Calcareous salts, apparently in chemical union with the *Ostein* (§ 194) that forms the basis of the osseous substance. In the midst of this granular substance, a number of dark spots are to be observed, the form of which is very peculiar. In their general outline, they are usually somewhat oval; but they send forth numerous radiating prolongations of extreme minuteness, which may be frequently traced to a considerable distance (Fig. 70). These spots, now known as the *osseous lacunæ* (but formerly termed the *Purkinjean corpuscles*, after the name of their discoverer), are highly characteristic of the true bony structure, being

* Extremity of Os femoris, showing cancellated structure :—*a*, thin layer of bone, in contact with the articular cartilage ; *b*, cancelli.

ver deficient in the minutest parts of the bones of the higher imals, although those of Fishes are frequently destitute of em. They were formerly supposed, from their dark appear-ce, to be opake, and to consist of aggregations of calcareous

Fig. 70.*



itter which would not transmit the light: but it is now quite rtain that they are open spaces, and that the radiating pro-igations from them, which are far smaller than the minutest pillary vessel, are *canaliculi* or delicate tubes. Of these canali-li, some may be seen to interlace freely with each other, whilst hers proceed towards the surface of the bony lamella; and thus system of passages, not by any means wide enough to admit e blood-corpuscles, but capable of transmitting the fluid elements the blood or matters selected from them, is established through e whole substance of the lamella.

277. The size and form of the *lacunæ* differ considerably in the veral Classes of Vertebrata, and even in some instances in the rders; so as to allow of the determination of the group to hich a bone belongs, by the microscopic examination of even a inute fragment of it. The following are the average dimensions the lacunæ, in characteristic examples drawn from the four incipal Classes, expressed in fractions of an inch:—

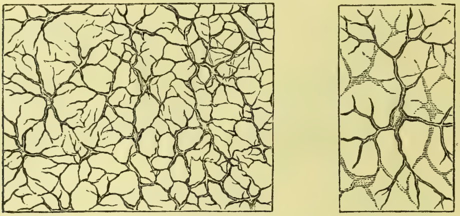
	Long Diameter.		Short Diameter.
Man . . .	1-1440 to 1-2400	....	1-4000 to 1-8000
Ostrich . . .	1-1333 to 1-2250	....	1-5425 to 1-9650
Turtle . . .	1-375 to 1-1150	....	1-4500 to 1-5840
Conger-eel . .	1-550 to 1-1135	....	1-4500 to 1-8000

he lacunæ of *Birds* are thus distinguished from those of ammals by their somewhat greater length and smaller breadth; it they differ still more in the peculiar tortuosity of their naliculi, which wind backwards and forwards in a very remark-ble manner. There is an extraordinary increase in length in the cunæ of *Reptiles*, without a corresponding increase of breadth; id this is also seen in some *Fishes*, though in general the lacunæ

* Lacunæ of Osseous substance, magnified 500 diameters:—*a*, central vity; *b*, its ramifications.

of the latter are remarkable for the angularity of their form and the fewness of their radiations, as is shown in Fig. 71, which represents the arrangement of the lacunæ and canaliculi in the

Fig. 71.*



bony scales of the *Lepidosteus* or 'gar Pike' (almost the only remaining representative of a large tribe of bony-scaled Fishes that formerly tenanted the seas), with which the bones of its internal skeleton perfectly agree in structure. The dimensions of the lacunæ in any bone do not bear any relation whatever to the size of the animal to which it belonged; but they bear a close relation to the size of the blood-corpuscles in the several Classes, as is particularly obvious in the case of the *Proteus* and other perennibranchiate Batrachia (§ 670), the extraordinary size of whose Blood-corpuscles has been already indicated (§ 216, Fig. 18, 10). The following are the dimensions of the lacunæ in three animals of this singular group:—

	Long Diameter.		Short Diameter.
Proteus	1-570 to 1-980	....	1-885 to 1-200
Siren	1-290 to 1-480	....	1-540 to 1-975
Menopoma . . .	1-450 to 1-700	....	1-1300 to 1-2100

278. The purpose of this penetration of the Osseous texture by such a complicated apparatus of tubuli, can scarcely be anything else than the maintenance of its vitality by the continual percolation of nutrient material, drawn into the system of lacunæ and canaliculi from the neighbouring blood-vessels. Every lacuna is occupied in the living Bone by a corpuscle of 'germinal matter,' which is the nutritive centre of the substance which surrounds it; and it is pretty certain that in the first formation of the osseous tissue these corpuscles were in mutual communication by means of their radiating extensions, like those of Connective tissue shown in Fig. 28. Whether these continue to occupy the cana-

* Section of the bony scale of Lepidosteus :—*a*, showing the regular distribution of the lacunæ and of the connecting canaliculi; *b*, small portion more highly magnified.

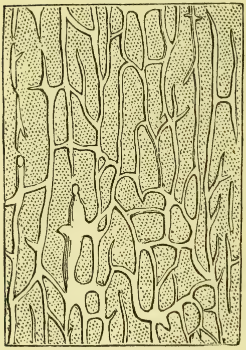
liculi, or by subsequent withdrawal from them leave these tubes freely pervious to liquids, can scarcely be stated with certainty; but by one means or the other the corpuscles of 'germinal matter' contained in the lacunæ are kept in relation with the nearest vascular surface (§ 280). Thus the nutrition of the ultimate Osseous texture is carried-on upon the same general plan with that of Cartilage, though differing in this;—that there is a provision in Bone for the ready transmission of nutrient matter through its texture by means of minute channels, which does not exist in Cartilage; a difference obviously required by the greater solidity of the substance of the former, which does not allow of the diffused imbibition that is permitted by the softer and moister nature of the latter. We shall presently find that these channels are only formed at a late stage of the development of bone, when the remaining tissue is acquiring its completest consolidation.

279. The cancelli are lined by a membrane derived from that of the cavity of the shaft, over which blood-vessels are minutely distributed; and by the materials drawn from these, each lamella is nourished through its system of lacunæ and radiating canaliculi. The cancelli, at the time of their formation in the fœtal bone, are entirely filled with cells, which appear (as will be presently explained) to be the descendants of the cells of the original cartilage; but in the adult bone they are for the most part occupied by fat-cells, like those which constitute the 'marrow' (§ 281). The vessels of the cancellated structure at the extremities of the long bones are derived from those of the medullary cavity, which is penetrated by large trunks from the exterior; and in the flat bones they form a system of their own, connected with the vessels of the exterior by several smaller trunks.

280. The solid Osseous texture which forms the cylindrical shafts of the long bones and the thick external plates of the denser flat bones, is not cut-off from nutritive action in the degree in which it might seem to be; for it is penetrated by a series of large canals, termed the *Haversian* (after Clopton Havers, their discoverer), which form a net-work in its interior (Fig. 72), and which serve for the transmission of blood-vessels through its substance. These canals, in the long bones, run for the most part in a direction parallel to the central cavity; and they communicate with this, with the external surface, with the cancelli, and with each other, by frequent transverse branches; so that the whole system forms an irregular network, pervading every part of the solid texture, and adapted for the establishment of vascular communications throughout. The diameter of the Haversian canals varies from 1-2500th of an inch to 1-200th or more; their average diameter may be stated at about 1-500th of an inch. They are lined by a membrane which is continuous with that of the external surface, and which carries this inwards (so to speak) to

form the lining membrane of the central cavity and of the cancelli; and the cavity of the tube encloses a single twig of an artery or vein.—Thus we may consider the whole Osseous texture as inclosed in a membranous bag, on which blood-vessels are minutely distributed, and which is so carried into the bone by involutions and prolongations, that no part of the latter is ever far removed from a vascular surface.

Fig. 72.*



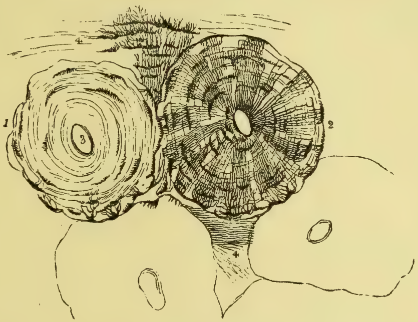
281. In the adult Bone, the cells which fill the remaining cavity of these canals secrete fatty matter; this is particularly evident in the case of the central cavity, which may be considered as an immensely-dilated Haversian canal, wherein they constitute the *medulla* or 'marrow.' It does not appear that this takes any active part in the nutrition of the bone; indeed in the bones of Birds the shaft is entirely hollow, and air is admitted into it from the lungs, so that its lining membrane is rendered subservient to the aëration of the blood.

282. The arrangement of the elementary parts of the Osseous substance around the Haversian canals is very interesting and beautiful. When a transverse section of a long bone is made, the open orifices of the longitudinal canals present themselves at intervals, sometimes connected by a transverse canal where the section happens to traverse this. Around each of these orifices we see the osseous matter arranged in a succession of concentric lamellæ separated by dark circles (Fig.73, 1, 2); and when one of these circles is minutely examined, it is found to be made up of a series of lacunæ analogous to those already described, these, however, being seldom or never so continuous as to form a complete circle. The long sides of the lacunæ are directed, the one towards the Haversian canal (3) in the centre, the other towards the circular row next beyond it. And when the course of the canaliculi is traced, it is found that these converge on the inner side towards the central canal, inosculating with those of the series next within, whilst those of the outer side pass outwards in a radiating or diverging direction, to inosculate with those of the series next external. Thus a complete communica-

* Vertical section of Tibia, showing the net-work of Haversian canals.

tion is formed, by means of this system of radiating canaliculi and intervening lacunæ, between the central canal and the outermost cylindrical lamella of bony matter; and each of these lamellæ derives its nourishment from the vessels of the central

Fig. 73.*



canal, through the lamellæ which intervene between itself and the vascular membrane lining that tube.

283. Thus every one of the Haversian canals is the centre of a cylindrical *ossicle*, which is complete in itself as far as its elementary structure is concerned, and which has no dependence on or connection with other similar ossicles. These are arranged, however, side by side, like sticks in a faggot; they are bound together by a thin cylinder of bone on the exterior of all, which derives its nourishment from the periosteum or enveloping membrane; in like manner, the hollow bundle is lined by a similar cylinder, which surrounds the great medullary cavity, and is nourished by its vascular membranes; and the spaces that here and there intervene between the ossicles, are filled-up with laminæ (4), which are portions of some former Haversian system of which the larger part has undergone removal by absorption (§ 295). By this arrangement the whole structure becomes possessed of great density

* Minute structure of Bone, as shown in a thin section cut transversely to the direction of the Haversian canals:—1. one of the Haversian canals surrounded by its concentric lamellæ; the lacunæ are seen between the lamellæ, but the radiating canaliculi are omitted; 2. an Haversian canal with its concentric laminæ, lacunæ, and radiating canaliculi; 3. the area of one of the canals; 4, 4, intervening lamellæ; between these lamellæ at the upper part of the figure, several very long lacunæ with their canaliculi are seen. In the lower part of the figure, the outlines of two other canals are given, in order to show their form and mode of arrangement in the entire bone.

and solidity.—The structure of the outer and inner tables of the skull, and of other thick solid layers of bone, is precisely similar; except that the Haversian canals have no such definite directions, and form an irregular network.

284. Thus we see that each of the lamellæ of bone surrounding an Haversian canal or bounding the cancelli, may be regarded as a repetition of the simple bony lamella (§ 275) which draws its nourishment direct from the vascular membrane covering its surface, by means of its system of lacunæ and canaliculi. The membrane lining the Haversian canals, cancelli, and central medullary cavity, is an internal prolongation of that which clothes the exterior; just as the Mucous membranes, with their extensions into glandular structures, are internal prolongations of the true Skin. Every Haversian canal and every cancellus are repetitions of each other in all essential particulars; their form alone being different. The central medullary canal is but an enlarged Haversian canal or cancellus. And the whole cylindrical shaft is a collection of 'ossicles,' each of which is a miniature representation of itself, being a hollow cylinder, with a central vascular cavity.

285. The principal features of the Chemical constitution of Bone are easily made evident. After all the accessory parts have been removed, and nothing remains but the real Osseous texture, this may be separated by simple processes into its two grand constituents,—the animal basis *Ostein*, and the Calcareous matter. The latter may be entirely removed by maceration of the bone in dilute Muriatic or Nitric acid; and a substance of cartilaginous appearance is then left, which, when submitted to the action of boiling water for a short time, is almost entirely dissolved into Gelatin, the solution forming a dense jelly on cooling. Gelatin may also be obtained by long boiling, or by digestion under pressure, from previously-unaltered bone; and the calcareous matter is then left in a friable condition. By submitting a bone to a heat sufficient to decompose the animal matter, without dissipating any of the earthy particles, we may obtain the whole calcareous matter *in situ;* but the slightest violence is sufficient to disintegrate it. The bones of persons long buried are often found in this condition; their form and position being retained until they are exposed to the air or are a little shaken, when they crumble to dust.

286. Although the flexible but tenacious model (so to speak) of a Bone, which is left after the solution of its calcareous component in dilute acid, is commonly said to consist of Cartilage, the term is inappropriate, since its substance has neither the structure nor the chemical composition of that tissue. The *Ostein* of Bone does not yield *Chondrin*, the characteristic principle of Cartilage, but *Gelatin*, the organic compound obtainable from White Fibrous tissue (§ 194). When examined microscopically, it does not exhibit any cartilage-cells, but presents the laminated texture of the ori-

ginal bone; and the lacunæ are still apparent, although their canaliculi cannot be readily traced. When a very thin lamella is peeled off the surface of the bone, it is found to have an indistinctly fibrous structure; being composed, as was first pointed out by Dr. Sharpey, of fibres in all essential respects resembling those of the White Fibrous tissue, which decussate with one another obliquely so as to form an exceedingly fine network, apparently adhering to each other at the points of intersection. The minute apertures between the reticulated fibres seem to give passage to the canaliculi.

287. The proportion of the Earthy matter of Bones to the animal basis may be differently stated, according as we include in our estimate of the latter the contents of the medullary cavity, the Haversian canals, and the cancelli; or confine ourselves to that portion only of the animal matter which is united with the calcareous element in the proper osseous tissue. The following are the results of some of the most recent and careful analyses of Human Bone, by Marchand and Lehmann: those of the former were made on the compact substance of the femur of a man aged 30; and those of the latter on the long bones of the arm aud leg of a man of 40 years of age.

	MARCHAND.	LEHMANN.
Organic matter.		
Cartilage insoluble in hydrochloric acid	27·23	
Cartilage soluble in hydrochloric acid	5·02	32·56
Vessels	1·01	
Inorganic matter.		
Phosphate of Lime	52·26	54·61
Fluoride of calcium	1·00	
Carbonate of lime	10·21	9·41
Phosphate of magnesia	1·05	1·07
Soda	·92	1·11
Chloride of sodium	0·25	0·38
Oxides of iron and manganese, and loss	1·05	·88
	100·00	100·00

According to Dr. Stark, the relative amount of the two elements in the proper Osseous tissue is subject to very little variation, either in the different classes of animals, or in the same species at different ages; the animal matter composing about one-third, or $33\frac{1}{3}$ per cent.; and the mineral matter two-thirds, or $66\frac{2}{3}$ per cent. The degree of hardness of Bone does not altogether depend, therefore, on the proportion of earthy matter they may contain; for the flexible, semi-transparent, easily-divided bones of Fish contain no larger an amount of animal matter than the ivory-like leg-bones of the Deer or Sheep. The usual analyses of Bone, however, have been made upon the former kind of estimate; and they show that the proportion of the earthy matter to the *whole* of the animal substance contained in bone, varies much in different animals, in the same animal in different ages, and even in different parts of the same skeleton. The reason of this will become apparent,

when the history of the growth of Bone has been explained; since there is a gradual filling-up of all the cavities at first occupied by fat-cells, vessels, &c., which does not cease with adult age, but continues during the whole of life. In this manner the bones of old persons acquire a high degree of solidity, but they become brittle in proportion to their hardness. From the same cause the more solid bones contain a larger proportion of bone-earth than those of a spongy or cancellated texture; the temporal bone, for example, containing $63\frac{1}{2}$ per cent., whilst the scapula possesses only 54 per cent. In the former of these bones, the proportion is nearly the same as that which exists in pure Osseous tissue, the amount of the remaining tissues which it includes being very small on account of the solidity of the bone: but the latter contains in its cancelli a large quantity of blood-vessels, fat-cells, &c., which swell the proportion of the animal matter from $33\frac{1}{3}$ to 46 per cent.

288. The Lime of bones is for the most part in the state of Phosphate, especially among the higher animals; the remainder is a Carbonate. In Human bones, the proportion of the latter seems to be between one-sixth and one-seventh of the whole amount of bone-earth. In the bones of the lower animals, however, the proportion of Carbonate is greater; and it is curious that in callus, exostosis, and other irregular osseous formations in the higher animals, the proportion of the Carbonate should be much greater than in sound bone. In caries, however, the proportion of the Carbonate is less than usual. The composition of the Phosphate of Lime in Bone is somewhat peculiar; eight equivalents of the base being united with three of the acid. According to Professor Graham, it is to be regarded as a compound of two tribasic phosphates; one atom of the *neutral* phosphate (in which one proportional of the acid is united with two of lime and one of water) being combined with two proportionals of the *alkaline* phosphate (in which one part of acid is united with three of the base), together with an atom of water which is driven-off by calcination.—Other mineral substances, such as phosphate of magnesia, oxides of iron and manganese, and chloride of sodium, are found in bones in small amount.

289. The first development of Bone is usually preceded by the formation of a Cartilaginous matrix, which occupies the place afterwards to be taken by the bone; and it is commonly considered that the bone is formed by the calcification of the cartilage substance. This, however, does not appear to be the case, as will be presently shown; and it would probably be more correct to say that the cartilage is superseded by bone. Moreover, bone is frequently developed in the substance of Fibrous membranes; and the structure produced by this *intra-membranous* ossification cannot be distinguished from that which is generated by the *intra-cartilaginous*.—We shall commence the history of the development

of Bone, with the period in which its condition resembles that of the permanent Cartilages. As already mentioned, there is no essential difference between the *temporary* and the *permanent* Cartilages in regard to their ultimate structure; the former, however, are more commonly traversed by vessels, especially when their mass is considerable. Still, these vessels do not pass at once from the exterior of the cartilage into its substance; but they are conveyed inwards along canals which are lined by an extension of the perichondrium or investing membrane, and which may thus be regarded as so many involutions of the outer surface of the cartilage. These canals are especially developed at certain points, which are to be the centres of the ossifying process; of these *puncta ossificationis*, we usually find one in the centre of the shaft of a long bone, and one in each of its epiphyses; in the flat bones there is one in the middle of the surface, and one in each of the principal processes. Up to a late stage of the Ossifying process, the parts which contain distinct centres are not connected by bony union, so that they fall apart by maceration; and even when they should normally unite, they sometimes remain separate,—as in the case of the Frontal bone, in which we frequently meet with a continuation of the sagittal suture down the middle, dividing it into two equal halves, which have originated into two distinct centres of ossification. It is interesting to remark that in the two lower classes of Vertebrata,—Fishes and Reptiles,—we find the several parts of the osseous system presenting in a permanent form many of the conditions which are transitory in the higher; thus the different portions of each vertebra, the body, lateral arches, spinous and transverse processes, &c., which have their distinct centres of ossification, but which early unite in Man, remain permanently distinct in the lower Fishes; the division of the frontal bone just adverted-to is constant amongst Fishes and Reptiles; and in those classes we meet with a permanent separation of the parts of the occipital and temporal bones, which, being formed from distinct centres of ossification, are at first disconnected in the higher animals.

290. During the formation of the *punctum ossificationis*, and the spread of the vessels into the cartilaginous matrix, certain changes are taking place in the substance of the latter, preparatory to its conversion into bone. Instead of single isolated cells, or groups of two, three, or four, such as we have seen to be characteristic of ordinary Cartilage (§ 256), we find, as we approach the ossifying centre, clusters made-up of a larger number (Fig. 74), which appear to be formed by a continuance of the same multiplying process as that already described. These are seen in transverse section to be disposed in a somewhat radiating manner around the orifices of the vascular canals; as is shown in a more advanced stage in Fig. 76. When we pass still nearer to the plane of ossification,

we see that these clusters are composed of yet greater numbers of cells, which are arranged in long rows whose direction corresponds with the longitudinal axis of the bone; these clusters are

Fig. 74.*

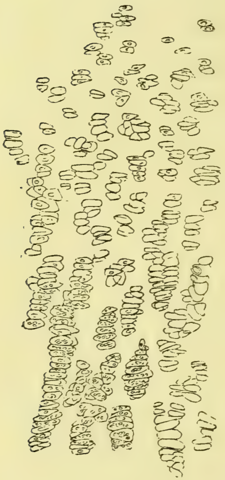


Fig. 75.†

still separated by intercellular substance, and it is in this that the ossific matter is first deposited (Fig. 75). Thus if we separate the Cartilaginous and the Osseous substance at this period, we find that the ends of the rows of Cartilage-cells are received into deep narrow cups of Bone, formed by the calcification of the intercellular substance between them (Fig. 76). Immediately upon the ossifying surface, the nuclei, which were before closely compressed, separate considerably from one another by the increase

* Longitudinal section of Cartilage near the seat of Ossification; each single cell having given origin to four, five, or six cells, forming clusters which are larger towards the bottom of the figure, their cells being more numerous and larger.

† The same Cartilage at the seat of Ossification, showing at its lower portion the clusters of cells arranged in columns, each of which is enclosed in a sheath of calcified intercellular substance.

of material within the cells; and the nuclei themselves become larger and more transparent. These changes constitute the first stage of the process of Ossification, which extends only to the calcification of the intercellular substance; in this stage there are no blood-vessels directly concerned. Of the bony lamellæ thus

Fig. 76.*

formed, some are speedily absorbed again, whilst others mark-out the boundaries of the cancelli and Haversian systems, which are afterwards to occupy a part of the space hitherto filled by the rows of Cartilage-corpuscles (§ 293).

291. Up to this point there is no essential difference in the accounts of those who have most carefully studied the process of Ossification; but in regard to the history of its subsequent stages there is much discrepancy; and this especially with respect to the origin of the bone-lacunæ, which some regard as metamorphosed cartilage-cells, others as the spaces originally occupied by their nuclei, whilst others do not regard them as in any way derived from the cartilage-cells, but consider them as a new formation.—According to the recent observations of Dr. Beale, the production of the first Osseous tissue in the flat bones of the Frog's skull, results from a direct conversion of the cartilage; the lacunæ and canaliculi being spaces left in the calcareous deposit, which are occupied by the nuclei of the cartilage-cells and their prolongations. This deposit is first laid down in the condition of isolated spherules between the corpuscles of 'germinal matter' (Fig. 77); and these corpuscles communicate with each other by radiating prolongations that pass between those spherules. The consolidation of the

* First Osseous network formed in the intercellular substance of Cartilage, around a vascular canal, as seen in transverse section.

intervening substance gradually becomes more complete, extending from without inwards, each corpuscle of 'germinal matter' being thus gradually reduced in size, and its connecting threads becoming more slender, until the ordinary system of lacunæ and canaliculi is completed (Fig. 78).—In the development of the long

Fig. 77.*

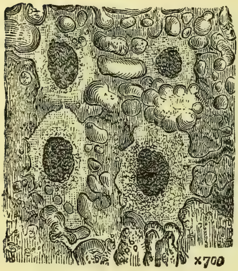
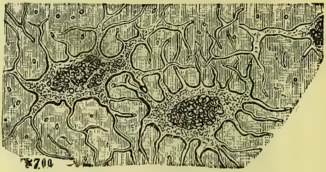


Fig. 78.†



bones of Mammalia, on the other hand, it seems certain that the spongy imperfectly-formed bone first produced by the calcification of the cartilaginous matrix, is gradually removed; giving place to a new osseous tissue of a more perfect structure, not formed from Cartilage, but generated by the calcification of an incipient Fibrous tissue. We shall probably form the most correct idea of this process by reverting to what has already been said of the system of Connective-tissue corpuscles (§§ 207, 227); and by regarding the Osseous substance in the light of 'formed material' generated on the surface of corpuscles of 'germinal matter' resembling the 'connective-tissue corpuscles' that give origin to the Simple Fibrous tissues (Fig. 28). If we suppose the interspaces of a sarcodic network, such as that formed by the pseudopodia of *Gromia* (Fig. 7), to be filled-up by shell-substance exuded from it, we should have a calcified tissue with lacunæ and canaliculi in all essential respects analogous to those of Bone; and such appears to be the character of the lamellæ which are progressively added to what remains of the substance first formed by the calcification of Cartilage,—by far the greater part of this, however, being removed by absorption, to make way for the spaces which are subsequently to be moulded into Haversian canals and cancelli (§ 293).

* Small portion of Frontal Bone of Frog in process of formation, showing globular form of particles of calcareous matter deposited between the germinal centres.

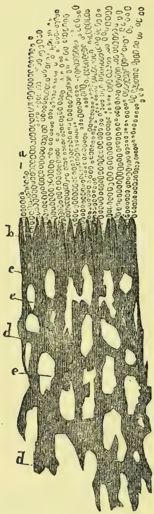
† Recently formed lacunæ and canaliculi from Frontal Bone of Frog.

292. Although, in a large proportion of the skeleton, the formation of Bone is preceded by that of Cartilage, yet such is by no means invariably or necessarily the case; for the flat bones, such as the scapula and those forming the roof of the skull, have usually only a centre of cartilage, beyond which the ossifying process extends in Membrane only. This membrane is chiefly composed of fibrous fasciculi, corresponding with those of the White Fibrous tissues: but amongst these are seen numerous corpuscles of 'germinal matter,' some about the size of blood-disks, but others two or three times larger; and a soft amorphous or faintly-granular matter is also found interposed amidst the fibres and corpuscles. The process of Ossification here seems essentially to consist in the consolidation of the fibres by earthy matter; for the first bony deposit is seen as an irregular reticulation, very loose and open towards its edges, and there frequently presenting itself in the form of distinct spicules, which are continuous with fasciculi of fibres in the surrounding membrane. The limits of the calcifying deposit may be traced by the opaque and granular character of the parts affected by it; and it gradually extends itself, involving more and more of the surrounding membrane, until the foundation is laid for the entire bone. Everywhere the part most recently formed consists of a very open reticulation of fibro-calcareous spicules, whilst the older part is rendered harder and more compact by the increase in the number of these spicules. As the process advances, and the plate of bone thickens, a series of grooves or furrows, radiating from the ossifying centre, are found upon its surface; and these, by a further increase in thickness, occasioned by a deposit of ossific matter all around them, are gradually converted into closed canals (the Haversian), which contain blood-vessels, and are lined by processes of the investing membrane. The lacunæ and canaliculi seem to take their origin in the corpuscles which are interspersed among the fibres; their prolongations extending themselves, and insinuatiug themselves through the spaces left between the interlacing fibres, whilst the process of calcification is going-on.

293. The first Osseous tissue which is formed by either of these processes has an irregular *cancellated* structure, analogous to that which is found at the extremities of the long bones in adults. This is gradually modified by changes which essentially consist in absorption and new deposition; for the absorptive process first unites minute areolæ into larger ones, by removing their partitions (Fig. 79); and upon the interior walls of these, new osseous lamellæ are now deposited, from materials supplied by the blastema they contain. It is by a process of this kind that the central medullary cavity is first formed in the bones of young animals. At an early period no such cavity exists, and its place is occupied by small cancelli; this is the permanent condition of

the bones in most Reptiles. The cancelli are gradually enlarged, however; and those within the shaft coalesce with one another until a continuous tube is formed, around which the cancelli are large, open, and irregular. At the same time, the diameter of the surrounding shaft is increasing by the process of superficial growth just described; so that the size of the medullary cavity at length becomes greater than that of the whole shaft when its formation commenced.—The aggregation of the osseous matter in a hollow cylinder, instead of a solid one, is the form most favourable to strength, as may be easily proved upon mechanical principles. The same arrangement is adopted in the arts, wherever it is desired to obtain the greatest strength with a limited amount of material.

Fig. 79.*



294. The growth of Bones takes place by the addition of new tissue to the part already formed; but this addition may take place in three modes,—namely by the development of new bone in the *cartilage* yet remaining between the different centres of ossification; by the development of new bone in the *membrane* covering the surface; and by the interstitial formation of new layers within the Haversian canals and cancelli of the part already formed, by which the requisite solidity is given to it. Of the first process we have the most characteristic example in the increase in length of a long bone, by the ossification of the cartilage which intervenes between the shaft and the epiphyses, and which continues to grow, up to the time of the final union of these parts. Thus it was long since proved by the experiments of Hales and Hunter, that the growth of a long bone takes place chiefly towards the extremities; for they found that, when metallic substances were inserted in the shaft of a growing bone of a young animal, the distance between them was but little altered after a long interval, whilst the space between the extremities of the bone had greatly increased. And it seems that, at a later period, when the epiphyses have become completely united to the shaft, an elongation continues to take-place, by the slow ossification of the arti-

* Vertical section through Cartilage and incipient Bone of the diaphysis of the Femur of an Infant a fortnight old:—*a*, piles of cartilage-cells; *b*, plane of ossification; *c*, close osseous network first formed; *d*, cancellated structure formed by absorption of parts of this; *e*, its cancelli filled with medulla.

cular cartilage.—Again, the bone is progressively augmented in thickness, by the gradual production of new osseous matter upon its surface; this production being effected by the conversion of the inner layer of the periosteum, the fibres of which are found to be continuous with those of the animal matrix of the surface of the bone.—And it is by the successive formation of new layers of osseous tissue, one within another, giving the appearance of concentric rings when the Haversian canals are cut across (Fig. 73), that the proportion of hard to soft parts in bone is gradually increased; the calibre of the Haversian canals being correspondingly diminished.

295. Even after the completion of the Bone, however, interstitial changes are continually taking-place in its substance, as in that of the softer tissues; old Haversian systems being partially or entirely removed by absorption, and new ones being developed in their place. And it is to the persistence of portions of those older Haversian systems which have undergone partial absorption, that we are to attribute the presence of those intervening laminæ (Fig. 73, 4) which fill up the spaces between the existing Haversian systems.

296. The difference in the relations of the Osseous substance to the vascular net-work, at different ages, — accounting for the variations in the rapidity of its nutrition and reparation,—is well displayed in the effects of Madder. This substance has a peculiar affinity for Phosphate of Lime; so that when the latter is formed by precipitation in a fluid tinged with madder, it attracts colour to it in its descent, and falls to the bottom richly tinted. Now when animals are fed with this substance, it is found that their bones become tinged with it, the period required being in the inverse proportion to their age. Thus in very young animals a single day suffices to colour the entire skeleton, for in them there is no osseous matter far from the vascular surfaces; when sections are made, however, of the bones thus tinged, it is found that the colour is confined to the immediate neighbourhood of the Haversian canals, each of which is encircled by a crimson ring. In full-grown animals, the bones are very slowly tinged; because the osseous texture is much more consolidated and less permeable to fluid than in earlier life; and because the vascular membrane lining the Haversian canals is removed further from the outer and older layers of osseous tissue which surround them, by the interposition of newer concentric layers which diminish the diameter of the canals. In the bones of half-grown animals, a part of the bone is nearly in the perfect condition, while a part is new and easily coloured; so that the action of this substance enables us to distinguish the new from the old.

297. The Regeneration of Bone, after loss of its substance by disease or injury, is extremely complete; in fact there is no other

structure of so complex a nature, which is capable of being so thoroughly repaired. Although the regenerative power appears to be so much less in Vertebrated animals than it is in the lower Invertebrata, yet it is probably not at all lower in reality; the new structures actually formed being as complex in the one case as in the other. It is nowhere, perhaps, more remarkably manifested, than in the re-formation of nearly an entire bone, when the original one has been lost by disease; all the attachments of muscles and ligaments, as well as the external form and internal structure, being ultimately found as complete in the new bone, as they originally were in that which it has replaced. Much discussion has taken-place in regard to the degree in which the different membranous structures that surround bone and penetrate its substance, participate in its regeneration; some having supposed the periosteum to have the power of itself forming new bone, others attributing the same power to the membrane lining the medullary cavities. It appears certain, however, that new Osseous tissue may be formed in a great variety of modes. Thus it may be produced through the intermediation of perfect Fibrous tissue, either when this previously existed as such (as the periosteum or interosseous membrane), or when it has been newly formed by the fibrillation of the plastic fluid effused as the material for reparation. The agency of the periosteum is seen in many cases of necrosis, in which that membrane has been completely detached from the dead shaft, and new bone has been generated from its interior. The ossification of a newly-produced fibrous membrane is believed by Mr. Paget to be the ordinary mode of reparation of fracture of the skull; and it takes-place in a manner essentially the same as that of the original intra-membranous development of bone. But new bone may also be formed, according to that most excellent observer, by ossification of the fibrous tissue in its rudimental state (§ 227). In abnormal bone-growths, it sometimes appears as if the tissue had been formed by the ossification of cells; but more commonly the calcification takes-place in an earlier stage of tissue-production, that of the 'nucleated blastema,' in which a granular osseous deposit is seen, which gradually increases so as to form the lamellæ of a fine cancellous texture, at the same time enclosing the nuclei, which seem to occupy the places afterwards to be left as lacunæ. It is seldom that the reparation of bone takes-place through the intermediation of cartilage; though this is occasionally formed, rather, perhaps, in the lower animals than in the human subject.

298. In the reparation of Bone after disease or injury, a plastic or organizable exudation is first poured-out from the neighbouring blood-vessels, and this forms a sort of bed or matrix, in which the subsequent processes take-place. At first, all new bone possesses a minutely cancellous structure, much like that of the fœtal bones

in their first construction; but this gradually assimilates itself to the structure of the bones which it repairs, its outer portions acquiring a more compact laminated texture, while its interior substance acquires wider cancellous spaces, and a perfect medulla. When the shaft of a long bone of an animal has been fractured through, and the extremities have been brought evenly together, it is found that the new matter first ossified is that which occupies the *central* portion of the deposit, and which thus connects the medullary cavities of the broken ends, forming a kind of plug that enters each. This was termed by Dupuytren, by whom it was first distinctly described, the *provisional callus.* This is usually formed in the course of five or six weeks, or less in young subjects; but at that period the contiguous surfaces of the bone itself are not cemented by bony union; and the formation of the *permanent callus* occupies some months, during which the provisional callus is gradually absorbed, and the continuity of the medullary canal restored, in the same manner as it was at first established. The permanent callus has all the characters of true bone.—It seems to have been established by the observations of Mr. Paget, however, that these statements do not usually apply to the case of Man; in whom, when the limb is kept at rest, the union between the fractured ends is accomplished by ossification of the substance connecting them, without the intermediation of a provisional callus; this being only formed when the portions of the bone are kept in continual movement.

299. The most extensive reparation is seen when the shaft of a long Bone is destroyed by disease. If violent inflammation occur in its tissue, the *death* of the fabric is frequently the consequence, —apparently through the blocking-up of the canals with the products of the inflammatory action, and the consequent cessation of the supply of nutriment. It is not often that the whole thickness of the bone becomes necrosed at once; more commonly this result is confined to its outer or its inner layers. When this is the case, the new formation takes-place from the part that remains sound; the external layers, which receive their vascular supply from the periosteum and from the Haversian canals continued inwards from it, throwing-out new matter on their interior, which is gradually converted into bone; whilst the internal layers, if *they* should be the parts remaining uninjured, do the same on their exterior, deriving their materials from the medullary membrane and its prolongations into their Haversian canals. But it sometimes happens that the whole shaft suffers necrosis; and as the medullary membrane and the entire system of Haversian canals have lost their vitality, reparation can then only take place from the periosteum, and from the living bone at the two extremities. This is consequently a very slow process; more especially as the epiphyses, having been originally formed as distinct parts from

the shaft, do not seem able to contribute much to the regeneration of the latter.

300. We next proceed to the *Teeth,* which are organs of mechanical attrition, developed in the first part of the alimentary canal, for the purpose of comminuting the food conveyed into it. We may best understand the structure and development of the Teeth in Man, by first inquiring into the characters presented by those of some of the lower animals, and the history of their evolution. In the fœtal Shark, the first appearance of the tooth is in the form of a minute papilla on the mucous membrane covering the jaws; the tissue of this papilla is composed of spherical cells, which are imbedded in a kind of gelatinous substance resembling that of incipient cartilage; whilst its exterior is composed of a dense, structureless, pellucid membrane. The cellular mass is not at first permeated by vessels; but a small arterial branch is distributed to each papilla, and spreads-out into a tuft of capillaries at its base. The papilla gradually enlarges, by the formation of new cells at the part immediately adjacent to the blood-vessels, which supply the material requisite for their development; and when it has acquired its full size, the process of *calcification* commences, by which it is converted into the substance of the tooth.

Fig. 80.*

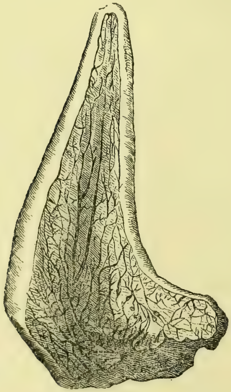
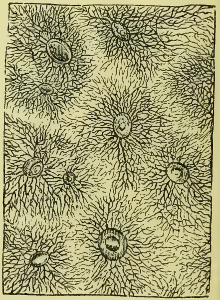


Fig. 81.†

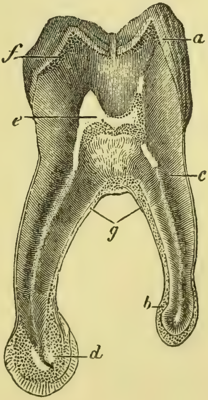


* Perpendicular section of Tooth of Lamna; moderately enlarged, shewing net-work of medullary canals.

† Transverse section of portion of Tooth of Pristis, more highly magnified, showing orifices of medullary canals, with systems of radiating and inosculating tubuli.

This substance, in the teeth of the Shark, as in those of many other Fishes, is extremely analogous to Bone; being traversed by a system of canals into which blood-vessels pass (Fig. 80), whilst each canal is surrounded by a set of tubuli which radiate into the surrounding solid substance (Fig. 81). These tubuli, however, do not enter lacunæ, nor is there any concentric arrangement around the medullary canals like that which exists in Bone (§ 282); but each system of tubuli is continued onwards through its own division of the tooth, the individual tubes sometimes giving off lateral branches, whilst in other instances their trunks bifurcate. The teeth are not prolonged beneath into fangs, but are simply set upon the bone of the jaw by their broad bases, and attached by the soft tissue; and the vascular canals of the teeth are actually continuous with the Haversian canals of the subjacent bone. This intimate connection is the more remarkable, as the Bone forms part of the internal or *neural* skeleton, and the Tooth of the external or *dermal*, its papilla being in all essential particulars analogous to a Hair-bulb.

Fig. 82.*

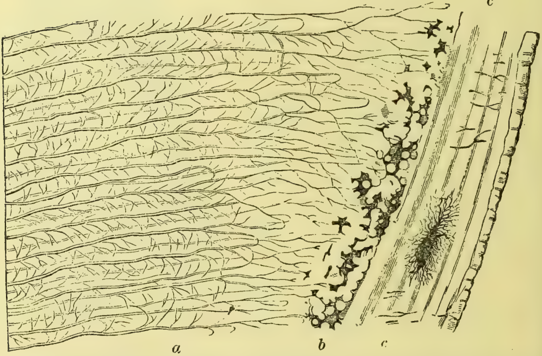


301. The Teeth of Man and of most of the higher animals are furnished with fangs by which they are implanted into the alveoli of the jaw; and are composed of three very different substances; *Dentine* (known as *ivory* in the tusk of the Elephant), *Enamel*, and *Cementum* or *Crusta Petrosa*. These are disposed in various methods, according to the purpose which the Tooth is to serve: in Man, the whole of the crown of the tooth is covered with Enamel (Fig. 82, *a*); its root or fang is covered with Cementum (*b*, *g*); whilst the substance or body of the tooth is composed of Dentine (*c*). In the molar Teeth of many Herbivorous animals, however, the Enamel and Cementum form vertical plates, which alternate with plates of Dentine, and present their edges at the grinding surface of the tooth; and thus the unequal *wear* of these substances,—the Enamel being the hardest, and the Cementum the softest,—occasions this surface to be always kept rough.

* Vertical section of Human Molar Tooth:—*a*, enamel; *b*, *g*, cementum or crusta petrosa; *c*, dentine or ivory: *d*, osseous excrescence, arising from hypertrophy of cementum; *e*, cavity; *f*, osseous lacunæ at outer part of dentine.

302. The *Dentine* consists of a firm substance, in which mineral matter largely predominates, though to a less degree than in the enamel. It is traversed by a vast number of very fine cylindrical branching wavy tubuli; which commence at the pulp-cavity (on whose wall their openings may be seen), and radiate towards the surface (Fig. 83, *a a*). In their course outwards, the tubuli occasionally divide dichotomously; and they frequently give off minute branches, which again send off smaller ones. These branchings are more frequent, the nearer the tubes approach the exterior of the dentine; and indeed it is only in the immediate neighbourhood of the enamel, that the dentinal tubes of the crown of the human tooth usually begin to ramify, although those of the neck and fang give off branches about the middle of their course. The terminal branches, on their arrival at the line of junction between the dentine and enamel, sometimes recurve and anastomose with contiguous tubes, sometimes pass across the line of junction and extend themselves for a short distance into the enamel and sometimes end in a fine point or in a rounded dilatation. In the fang of the tooth, there is a much more frequent anastomosis among the tubuli; and of their terminal branches, some lose themselves in their intertubular tissue, others dilate into radiating lacunæ not unlike those of bone, others anastomose and form loops with the branches of adjacent tubes, whilst others pass into the interspaces that exist among the large

Fig. 83.*

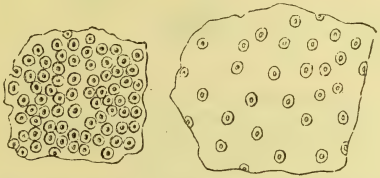


* Section through the fang of a Molar Tooth:—*a*, *a*, dentine traversed by its tubuli; *b*, *b*, nodular layer; *c*, *c*, cementum.

granules that form the outer surface of the dentine of the fang (Fig. 83, *b b*), and some of these may even extend themselves into the cementum and communicate with its radiating cells. When the dentinal tubuli are examined in transverse section (Fig. 84), the aperture of each is seen to be surrounded by an annulus which separates its parietes from the intertubular tissue; and it can be further seen better in transverse than in longitudinal sections, that the distances of the tubuli from each other vary greatly; the tubuli being closest, and the intertubular tissue consequently the smallest in amount, in the crown of the tooth (A); whilst in the dentine of the fang the intertubular tissue forms the larger element (B). The internal diameter of the tubuli in the largest part averages about 1-10,000th of an inch, but when their parietes are included, it measures about 3-10,000ths;

Fig. 84.*

A B



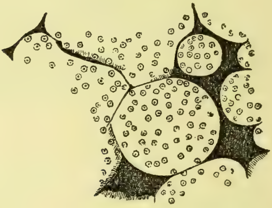
their smallest branches are immeasurably fine. The intertubular tissue of dentine, as of bone, is affirmed by Mr. Tomes to be granular throughout; the granules being nearly spherical, and measuring from 1 to 3-10,000ths. Near the surface of the dentine in the fang, and occasionally in other parts of the tooth, it presents the appearance of an aggregation of nodular concretions, with irregular interspaces between them (Fig. 83, *b b*); each of these, when divided transversely and highly magnified, is seen to be traversed by several dentinal tubes (Fig. 85). In other parts of the tooth, it not unfrequently happens that the dentinal substance is traversed by lines which divide it into more or less regular polygonal areæ; and this appearance (Fig. 92), which is normal in the teeth of many of the lower animals, has been interpreted as indicative of the persistence of the boundaries of the original cells of the pulp. A more satisfactory explanation of it, however, will be presently given (§ 314).

303. The preceding description of the structure of Dentine is applicable only to the *dry* tooth; for in the living state the

* Transverse sections of Dentine; A, from the crown; B, from the fang; showing the orifices of the tubes, and the thickness of their walls.

tubuli are occupied by prolongations of the protoplasmic substance which occupies the pulp-cavity (§ 314); and these prolongations appear capable of conveying the materials of the dentinal substance which they take-up from the blood vessels, and of depositing them at a distance from their source. For although a Tooth, when once fully formed, undergoes little or no change, there is

Fig 85.*



evidence that it possesses a certain power of repairing the effects of disease; a new layer of hard matter being sometimes thrown out on a surface which has been laid bare by Caries. It has been found, too, that the Dentine is sometimes tinged by colouring matters contained in the blood. This is most evident when a young animal is fed upon madder during the period of the formation of the tooth; but even in an adult some tinge will result from a prolonged use of this substance; and it has been noticed that the teeth of persons who have long suffered from Jaundice, sometimes acquire a tinge of bile.

304. Although in the most characteristic form of Dentine no blood-vessels exist, yet there are certain species, both among Mammals, Reptiles, and Fishes, in which the Dentine is traversed by cylindrical prolongations of the central cavity, conveying blood-vessels into its substance; and the presence of these medullary canals, giving to the dentine a vascular character, thus increases its resemblance to Bone.—The central portion of the pulp is sometimes converted into a substance still more nearly resembling bone, having its stellate lacunæ as well as its vascular canals. This change is normal or regular in certain animals, as in the extinct Iguanodon and Ichthyosaurus, and in the Cachalot or Sperm-whale; and the ossified pulp bears a close resemblance to the bones of the respective animals, although it is not formed in

* Portion of the nodular layer of the Dentine of the fang, more highly magnified.

continuity with them. A similar change sometimes occurs in the Human tooth; the pulp-cavity becoming the seat of a secondary development of dentinal substance, by which its cavity is greatly contracted or even obliterated. This is seen especially in the teeth of old persons, or in those which have been much worn; and also in those that are the subjects of caries, a layer of 'secondary dentine' being formed between the soft pulp and the spot towards which the disease is advancing. This 'secondary dentine' is not so regular in its structure as the 'primary,' and more resembles that of the lower animals; for it is usually traversed by 'vascular canals' proceeding from the pulp-cavity, and the tubuli radiate from these instead of from one common centre. Moreover, the presence of stellate lacunæ, resembling those of bone, is much more common in this substance than in true dentine; so that, both in the presence of the vascular canals which represent the Haversian, and also in its own texture, this substance may be considered as intermediate between Dentine and Bone.

305. The *Enamel* (Fig. 86) is composed of solid prisms or fibres (Fig. 87, B), from about 1-5600th to 1-3300th of an inch in diameter, arranged side by side, and closely adherent to each

Fig. 86.*

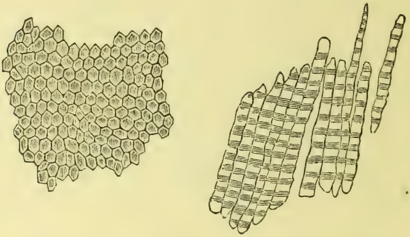
other; their direction is for the most part vertical to that of the dentinal surface on which they rest, so that their length corresponds with the thickness of the layer which they form; and the two surfaces of this layer present the ends of the prisms, which are usually more or less regularly hexagonal (Fig. 87, A). The course of these prisms is generally wavy (Fig. 86), but their curves are for the most part parallel to each other; not unfrequently, however, the curves separate from each other, or even decussate, the intervening spaces being then filled-in with shorter

* Vertical Section of the Enamel of the Human Molar Tooth.

fibres. The enamel-prisms are usually marked by transverse striæ (Figs. 86, 87 B), the distance of which is about equal to the diameter of the fibre. The Enamel is ordinarily destitute of tubuli; but Mr. Tomes has shown that it is occasionally penetrated by prolongations of the tubuli of the dentine, and that this peculiarity, which is occasional and abnormal in Man, is characteristic of the teeth of many Marsupials. In the perfect state, the Enamel

Fig. 87.*

A B



contains but an extremely minute quantity of animal matter; but if a young tooth be examined, it is found that, after the calcareous matter of the tooth has been dissolved away by an acid, there remains a delicate prismatic matrix, resembling that of the prismatic shell-structure in Mollusca (§ 267). The Enamel, when once formed, appears to undergo scarcely any further change; and it possesses no power of self-regeneration after loss of substance by injury or disease.

306. In density and resisting power the Enamel far surpasses any other organized tissue, and approaches some of the hardest of mineral substances. In Man and in Carnivorous animals it covers the crown of the tooth only, with a simple cap or superficial layer of tolerably uniform thickness (Fig. 82, *a*), which follows the surface of the dentine in all its inequalities; and its component prisms are directed at right angles to that surface, their inner extremities resting in slight but regular depressions on the exterior of the dentine. In the molar teeth of many Herbivorous animals, however, the Enamel does not form a continuous layer over the surface of the crown, but presents itself in variously-disposed ridges, which are the edges of vertical plates alternating with those of Dentine and Cementum (§ 301). And in the large front teeth of the Rodents (§ 312), a constant sharp-

* A, Transverse section of *Enamel*, showing the hexagonal form of its prisms; B, separated prisms.

ness of edge is provided for by the restriction of the Enamel to the anterior surface, and by the diminution in the hardness of the Dentine towards the posterior aspect of the tooth; the effect of *wear* being thus to maintain a sharp cutting edge of Enamel in front, suppported by the less brittle Dentine, which slopes away behind like the end of a chisel.—The Enamel is the least constant of the dental tissues. It is much more frequently absent than present in the teeth of the class of Fishes; it is wanting in the entire order of Ophidia (Serpents) among existing Reptiles; and it forms no part of the teeth of the Edentata (Sloths, &c.) and Cetacea (Whales) amongst Mammals.

307. The *Cementum* or *Crusta Petrosa* corresponds in all essential particulars with Bone, possessing its characteristic lacunæ, and being also traversed by vascular medullary canals, which pass into it from its external surface, wherever it occurs in sufficient thickness (as in the exterior of the tooth of the extinct Megatherium, and in the thick plates interposed within the islets of Enamel in the teeth of Ruminants, Rodents, &c.); in Man, however, in whose teeth the Cementum is very thin, such vascular canals do not usually exist, though Mr. Tomes states that he has occasionally met with them. The Cementum was formerly supposed to be restricted to the compound teeth of Herbivorous animals; and its presence in the simple teeth of Man and the Carnivora can be shown only by the application of the Microscope. In the latter it forms a layer which invests the fang, and which decreases in thickness as it approaches the crown of the tooth (Fig. 82, *b*, *g*); at the time of the first emersion of the tooth it covers the crown also with a very thin lamina, which is speedily worn away by use; on the other hand, its thickness around the apex of the fang often undergoes a subsequent increase, especially when chronic inflammation and thickening take place in the membranous contents of the socket (*d*). When the tooth is first developed, the Cementum envelopes its crown, as well as its body and root; but the layer is very thin where it covers the Enamel, and being soft it is soon worn-away by use. In the teeth of many Herbivorous Mammals, it dips-down with the Enamel to form the vertical plates of the interior of the tooth; and in the teeth of the Edentata, as well as of many Reptiles and Fishes, it forms a thick continuous envelope over the whole of the surface, until worn-away at the crown.—The following are the results of Von Bibra's analyses of the component structures of Human Teeth:—

Incisors of Adult Man.

	Dentine.	Enamel.	Cementum.
Organic matter	28·70	3·59	29·27
Earthy matter	71·30	96·41	70·73
	100·00	100·00	100·00

The proportion of these two components varies considerably in different species; thus the organic basis of the Elephant's tusk forms as much as 43 per cent. of the whole. It would seem even to vary considerably in different individuals of the same species; thus in the molar teeth of one man, Von Bibra found the organic matter to constitute as little as 21 per cent., whilst in another it was 28.—The following analyses afford a more particular view of the components of each substance:—

Molars of Adult Man.

	Dentine.	Enamel.
Phosphate of Lime, with trace of fluate of lime	66·72	89·82
Carbonate of Lime	3·36	4·37
Phosphate of Magnesia	1·08	1·34
Other Salts	0.83	0·88
Chondrin (?)	27·61	3·39
Fat	0·40	0·20
	100·00	100·00

Incisors of Ox.

	Dentine.	Enamel.	Cementum.
Phosphate of Lime, with trace of fluate of lime	59·57	81·86	58·73
Carbonate of Lime	7·00	9·33	7·22
Phosphate of Magnesia	0·99	1·20	0·99
Salts	0·91	0·93	0·82
Chondrin (?)	30·71	6·66	31·31
Fat	0·82	0·02	0·93
	100·00	100·00	100·00

308. The development of the Teeth of Man commences in a manner essentially the same as that of the teeth of the Shark (§ 300); namely, in the formation of a *papilla* for each tooth on the surface of the Mucous membrane of the mouth. But the dental papillæ in Man and the higher animals are afterwards found at the bottom of open *follicles;* and the orifices of these follicles are subsequently closed-in, so that they become converted into *capsules*. It is not until this *capsular* stage has been attained, that the calcification of the papillæ takes-place; and it will be desirable, therefore, in the first place to sketch the process by which their capsular investments are generated.—At the *sixth* week of fœtal life a deep narrow groove may be perceived (Fig. 88, *b*) in the upper jaw of the Human embryo, between the lip (*a*) and the rudimentary palate; this is speedily divided into two by a ridge, which afterwards becomes the external alveolar process; and it is in the inner groove, which is termed the 'primitive dental groove,' that the germs of the teeth subsequently appear. At about the *seventh* week there is seen on

the floor of this groove, shown in transverse section at *a*, Fig. 89, on each side of the jaw, an ovoidal papilla, *b*, which is the germ of the anterior temporary Molar. Soon afterwards the papillæ of the Canines make their appearance, next those of the Incisors, and finally those of the posterior temporary or 'milk' Molars. During the *tenth* week, processes from the sides of this 'primitive dental groove,' particularly the external one, begin to approach one another, so as to divide it by their meeting into a series of open follicles, at the bottom of which the papillæ may still be seen. At the *thirteenth* week, all the follicles being completed,

Fig. 88.*

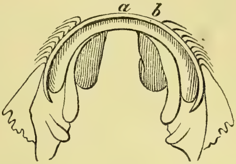
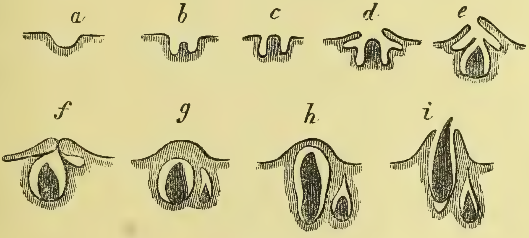


Fig. 89.†



the papillæ, which were at first round blunt masses of cells, begin to assume forms more characteristic of the teeth which are to be developed from them; and by their rapid growth, they protrude from the mouths of the follicles (*c*). At the same time, the edges of the follicles are lengthened into little valve-like processes, or *opercula*, which are destined to meet and form covers to the follicles (*d*). There are two of these opercula in the Incisive follicles, three for the Canines, and four or five for the Molars. And by the

* Upper jaw of Human Embryo at sixth week; showing at *b* the primitive dental groove, behind *a* the lip.

† Successive stages of the development of the Deciduous or Temporary Teeth, and of the origin of the capsules of the Permanent set:—*a*, Primitive dental groove, seen in transverse section; *b*, origin of dental papilla from its floor; *c*, papilla projecting from the mouth of its follicle; *d*, *e*, formation of the opercula, the meeting of which converts the follicle into a closed capsule; *f*, capsule completed, with incipient formation of cavity of reserve; *g*, *h*, *i*, formation of capsules and papillæ of permanent teeth from cavity of reserve, and eruption of milk-teeth.

fourteenth week, the two lips of the dental groove meet over the mouths of the follicles, so as completely to enclose each papilla in a distinct capsule (*e*).

309. At this period, before the calcification of the primitive pulps commences, a provision is made for the production of the 'permanent' teeth; whose capsules originate in buds or offsets from the upper part of the capsules of the temporary or 'milk' teeth (*f*). These offsets are at first in the condition of open follicles, communicating with the cavity of the primitive tooth; but they are gradually closed-in, and detached altogether from the capsules of the milk-teeth (*g*, *h*, *i*).

310. We have thus seen that the history of the first development of the Human teeth may be divided into three stages, the *papillary*, the *follicular*, and the *saccular*. The 'papillary' corresponds precisely with the complete mode of dental development in the Shark and other Fish,—as already mentioned. The 'follicular,' which commences with the enclosure of the papillæ in open follicles, and terminates when the papillæ are completely hidden by the closure of the mouths of these follicles, has also its permanent representation in the development of the teeth of many Reptiles and Fishes; the primitive papillæ of which, though enclosed in follicles, are never covered-in at the summit, and thus free themselves from their envelopes by simply growing upwards through their open mouths. But in Man, and in all other animals which agree with him in going-on to the 'saccular' stage, there must also be an *eruptive* stage, which consists in the bursting-forth of the tooth from the enclosing capsule; the summit of the tooth being carried against the lid of the sac by the growth of its root (Fig. 89, *h*). By the continuance of the same growth, the teeth are caused to penetrate the gum, and are gradually raised above its surface (*i*).

311. All the permanent teeth, which are destined to replace the temporary set, originate, as already stated, in buds or offsets from the capsules of the latter. But behind the last temporary Molars, which are replaced by the permanent Bicuspids, three permanent Molars are to be developed on each side of either jaw. The *first* of these is formed on precisely the same plan with the milk-teeth; but is not completed until a later period. The capsule of the *second* is formed at a later period from that of the first, by a process of 'budding' exactly analogous to that by which the other permanent capsules are formed from the corresponding temporary; and at a still later period, the capsule of the *third* permanent molar is formed as a bud from that of the second. The evolution of this molar does not usually take-place until the organism has acquired its full development; and the process of budding then ceases in Man,—being limited to a single act of reproduction in the case of the ordinary Milk-teeth, and to a

double one in that of the first permanent Molar. In many animals of the lower classes, however, the process goes-on through the whole of life without any limit; the newly-formed teeth, however, usually taking the places of those of the previous set, and not being developed at their sides like the second and third permanent molars of Man. It is in this manner that the continual renewal of the teeth is effected in those Reptiles and Fishes whose dentition goes-on to the saccular stage; in those at which it stops at the papillary, the successive teeth are formed from new and independent papillæ. The analogy between the continued succession of teeth in the lower Vertebrata, by the gemmiparous reproduction of their capsules, and the development of the capsules of the permanent teeth of Man from those of the temporary set, is made further evident by the fact that a *third* set occasionally makes its appearance in persons advanced in life; the development of which would not be intelligible if we could not refer it to the continuance of the same process in the other capsules, as that which regularly takes-place to a limited extent in the permanent molars of Man, and which goes-on without limit through the whole lives of the lower Vertebrata.

312. We occasionally meet with teeth in certain Mammalia,—such as the tusks of the Elephant, the two large front teeth of the Rodents, and the grinders of the Sloths,—which are constantly in a state of growth, their pulps being *persistent*, and not being closed-in by the growth of fangs. In such teeth the base of the pulp remains unconverted, and a new development of cells is continually taking-place in that situation; these new cells are in their turn converted into dentine, in continuity with that previously formed; and thus the tooth or tusk is continually lengthening at its base, in a degree which compensates for its usual wear at its summit. If anything should prevent that wear,—as when the opposite tooth has been broken-off,—there is an absolute increase in the length of the tooth from the continued growth at its base, which may become a source of great inconvenience to the animal. There is nothing in the Human subject at all analogous to this mode of development from persistent pulps; the process being checked by the closure of the root around the base of the pulp, which obstructs the supply of blood it receives. The chief exception to the rule that no Reptiles or Fishes have permanent teeth, is found in the curious *Dicynodon*, an extinct Reptile which had two large tusks growing from persistent pulps.

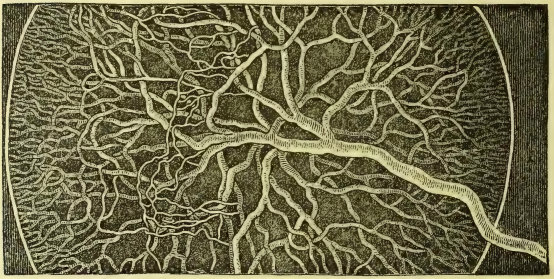
313. The following table shows the usual periods at which the different teeth of the two sets first show themselves above the gum. It must be borne in mind, however, that these periods are subject to very great variation; and that the average alone can therefore be expressed.

Temporary or Deciduous Teeth.	Months.
Central Incisors .	7
Lateral Incisors .	8—10
Anterior Molars .	12—13
Canines . . .	14—20
Posterior Molars .	18—36

Permanent Teeth.	Years.
First Molars .	$6\frac{1}{2}$ to 7
Central Incisors .	7 — 8
Lateral Incisors .	8 — 9
First Bicuspids .	9 —10
Second Bicuspids .	10 —11
Canines . .	12 —$12\frac{1}{2}$
Second Molars .	$12\frac{1}{2}$—14
Third Molars .	16 —30

314. We shall now briefly trace the mode in which the several structures of which the Teeth are composed are developed from the substance of the dental papilla. This substance at first consists of a material very much resembling that of rudimentary connective tissue; being composed of delicate fibres or bands, the meshes of which are occupied with a thick clear homogeneous fluid or plasma, scattered through which are a number of nucleated cells; the whole being enclosed in a dense, structureless, pellucid membrane, which is continuous with the basement-membrane of the mucous lining of the mouth, and has received the name of *Membrana preformativa.* The papilla is copiously supplied with blood-vessels, which originate in a trunk that enters its base (Fig. 90), and then ramify and spread through its whole substance, at

Fig. 90.*

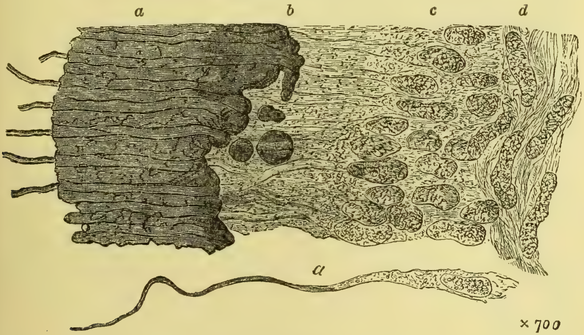


last forming a capillary network which terminates in loops near its apex. These vessels are accompanied by nerves, which also have looped terminations.—The changes in which the production of Dentine consists, commence near the coronal surface of the

* Vessels of Dental Papilla.

papilla; where the cells of the pulp lying beneath its investing membrane are found to have undergone enlargement, and to be thickly scattered at pretty regular intervals through a somewhat granular uniting medium, the intermediate connective tissue having now disappeared. The blood-vessels now begin to retreat from the coronal surface of the papilla, in the same manner as from the synovial surface of the articular cartilages (§ 258).—The condition of the 'tooth-pulp' at this period may be likened to that of incipient cartilage; each of its so-called 'cells' being in reality a segment of 'germinal matter' not invested by a proper membrane, but inclosed in the 'formed material' which has been produced from its peripheral portion; the 'formed material' of the separate segments constituting what is commonly designated the 'intertubular substance.' At the plane of calcification (Fig. 91, *b*), the segments of 'germinal matter' are described by Prof. Beale as giving off long processes, which extend themselves into

Fig. 91.*

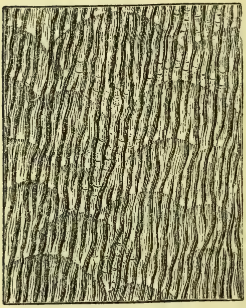


the 'formed material' in the direction of the surface of the tooth; and it is in the intervals between these that the calcification of the matrix or 'formed material' takes place, as shewn at *a*. The calcareous salts are at first deposited in detached nodular masses (as seen at the junction of the light and dark portions of the figure), which are usually augmented by additional deposit at their margins, until they completely coalesce, so as to form a

* Thin section of the inner portion of the Dentine, and of the surface of the Pulp, of an adult Incisor Tooth :—*a*, portion in which calcification is complete, showing separate globular masses at the line of junction with the uncalcified substance, *b*; at *c* are seen oval masses of germinal matter (cells), with formed material on their outer surface; *d*, terminal portions of nerve-fibres.

continuous mass of calcified dentine, penetrated by the sarcodic extensions of the segments of germinal matter forming the tooth-pulp. But we sometimes find this coalescence incomplete, especially at the external surface of the crust of dentine (Fig. 83, *b*); and when the portions of uncalcified matrix left between the nodules have shrunk by the drying-up of the tooth, air-spaces are left, which give the black appearance shewn in Figs. 83, 85. And where there are no absolute intervals between the nodules, their junctions are sometimes so obvious as to give rise to an appearance that has been supposed to indicate the boundaries of the original cells of the pulp (Fig. 92). After the matrix of the dentine has undergone calcification, the processes of 'germinal matter' by which it is penetrated gradually undergo conversion at their surface into 'formed material;' this gives origin to the calcification of what have been described as the 'proper walls' of the dentinal tubuli, which, being solidified at a later period than the surrounding inter-tubular substance, appear distinct from it (Fig. 84). These tubes continue for a time to be occupied throughout by the processes of sarcodic substance extended from the tooth-pulp, which are now, however, reduced in diameter; but these processes gradually shrink on the completion of the changes to which they are subservient; and at last are only found in the inner or last-formed portion of the dentine.—The tooth-pulp, in the healthy tooth, retains to a certain degree its formative power during the whole of life; as is made evident by the facts already mentioned (§ 303).

Fig. 92.*



315. The opinion has long prevailed that the *Enamel* is not formed in the substance of the dental papilla, but that it is produced by the calcification of a layer of prismatic epithelium-cells on the *exterior* of the *membrana preformativa* or basement-membrane forming the boundary of the papilla. The lining membrane of the dental capsule is extremely vascular; and between this and the dental papilla which it encloses, there is at an early period a considerable space occupied by a loose tissue consisting of a mesh-work of stellate cells, the areolæ between which are filled-up by an albuminous fluid. This tissue has received the name of 'enamel-pulp'; and it has been described as passing into the layer of pris-

* Oblique section of Dentine of Human Tooth, highly magnified, showing the parallel tubuli, and persistent indications of the original nodular calcification.

matic or cylinder epithelium which forms the basis of the enamel. —It seems next to certain, however, from the observations of Huxley, Lent, and others, that the Enamel is formed *beneath* the *membrana preformativa*, so that it really constitutes the most external of the layers produced by the calcification of the tooth-pulp; and it is also clear that the so-called 'enamel-pulp' is not an epithelial structure, but that it is a vascular spongy growth from the mucous lining of the capsule, in all respects analogous to the early condition of ordinary Connective tissue, into which tissue it is finally metamorphosed. It is quite possible that this substance may contribute indirectly to the formation of the Enamel, by supplying nutrient material to the surface of the dentinal papilla, which may be absorbed through its investing membrane; but as it seems clear that it can take no other share in its production, the name 'enamel-pulp' is altogether inappropriate, and should be discarded. The persistence of the original structureless membrane (*membrana preformativa*) which bounds the papilla, may be demonstrated by the action of dilute acid upon the surface of a tooth which has not long emerged from its capsule; as was first shewn by Nasmyth, although he erroneously conceived this membrane to be the persistent capsule. If the ordinary doctrine were correct, the place of the *membrana preformativa* would be between the external surface of the dentine and the internal surface of the enamel; and that no such impervious septum exists in that situation, is made evident by the frequency of the passage of the tubuli of dentine into the substance of the enamel, as already mentioned (§ 305). Whether the calcareous prisms which constitute the enamel-fibres are deposited in the interior of elongated cells of the dentinal pulp, or whether they are deposited in the midst of a homogeneous substance which their apposition (as in the case of the 'prismatic shell-substance,' § 267,) converts into the semblance of a cellular membrane, is a question not yet settled.

316. The *Cementum* is formed in the same situation as the Enamel,—that is, immediately beneath the *membrana preformativa*,—on those parts of the tooth which are not invested by the Enamel; and it is not unfrequently found that the one substance passes gradationally into the other, the fibrous structure characteristic of the Enamel being combined with the lacunar structure characteristic of the Cement.

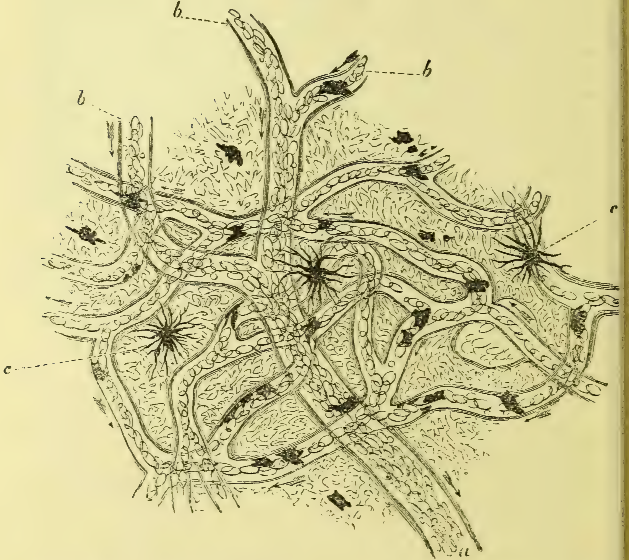
6. *Of the Simple Tubular Tissues;—Capillary Blood-vessels and Absorbents.*

317. All the Animal Tissues derive the materials of their growth and renovation from the nutrient fluid, which is brought into a more or less close relation with their elementary parts by means

of *Capillary Blood-vessels.* These seem to have a claim to be regarded as among the elementary parts of the fabric; since they are formed quite independently of the larger trunks, and have little in common with them in their function. All those changes which take place between the blood and the surrounding parts, whether ministering to the operations of Nutrition, Secretion, or Respiration, occur during its movement through them; and the function of the larger trunks is merely to bring to them a constant supply of fresh blood, regulated according to the demand created by the actions to which it is subservient, and to remove the fluid which has circulated through them.

318. In Man, as in all the higher Animals,—in the adult condition at least,—the Capillary circulation is carried-on, with

Fig. 93.*



scarcely any exception, through tubes having distinct membranous parietes. These tubes commonly form a minutely-anastomosing

* Capillary plexus in a portion of the web of a Frog's foot:—*a*, trunk of vein; *b, b*, its branches; *c, c*, pigment-cells.

network (Fig. 93), into which the blood is brought by the ramifications of the arteries on one side, and from which it is returned by the radicles of the veins on the other. The walls of the tubes are composed of a delicate structureless membrane, resembling that of the wall of fully-formed Cells, or the 'sarcolemma' of Muscular fibre (§ 327); and this seems clearly to possess considerable elasticity, though there is no decided evidence that it is contractile. The Capillaries are distinguished from the smallest arteries and veins by the absence alike of any external investment and of any epithelial lining. The size varies in different animals, in accordance with that of their blood-corpuscles; thus the Capillaries of the Frog are, of course, much larger than those of Man. The diameter of the latter appears, from the measurements of Weber, Müller, and others, to vary from about the 1-3700th to the 1-2500th of an inch; the extremes, however, are stated by Kölliker at as little as 1-5600th and as much as 1-1870th of an inch. As the diameter of the Human capillaries can only be examined after death, it is probable that these statements are not altogether exact, particularly as tubes of the smallest of the above sizes would not admit ordinary blood-corpuscles. The dimensions of the individual vessels, indeed, are by no means constant; as may be seen by watching the Circulation in any transparent part for some little time. Putting aside these general changes in diameter, which result from circumstances affecting all the capillaries of a part, it may be observed that a single capillary will sometimes enlarge or contract by itself without any obvious cause. Thus the stream of blood will sometimes be seen to run into passages which were not before perceived; and it has hence been supposed that they were new excavations, formed by the retreating or removal of the solid tissue through which it passes. But a more attentive examination shows that such passages are real capillaries, which did not at the time of the first observation admit the stream of blood-corpuscles, in consequence of the contraction of their calibre or of some other local impediment; and that they are brought into view by the simple increase in their diameter.

319. The opinion was long entertained that there are vessels specially adapted to supply the white or colourless tissues; carrying from the arteries the 'liquor sanguinis,' and leaving the corpuscles behind through inability to receive them: this supposition is altogether groundless. Another account has been recently given by Virchow of the distribution of nutrient material through the Connective tissues: this he believes to be accomplished by the intermediation of the 'connective tissue corpuscles,' which he regards as *cells* with radiating tubular extensions that inosculate with each other, and thus form a network of tubuli through these tissues, closely resembling the canalicular network of Bone (§ 276). The Author agrees with Prof. Beale, however, in regarding these

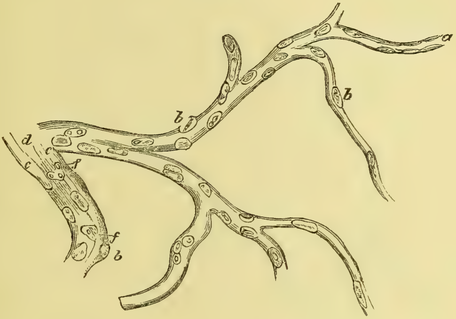
corpuscles and their extensions, not as cells and tubuli, but as segments of sarcodic substance (§ 227); and in likening their distribution of nutrient material to that which is effected by the change in the relative position of the particles of the sarcode itself in the pseudopodia of a Rhizopod (§ 201).

320. Some of the white tissues, as Cartilage, are altogether destitute of vessels; and in others the supply of blood is so scanty as not to communicate to them any decided hue; so that there is, in fact, no essential difference between the nutrition of the non-vascular tissues, and that of the islets in the midst of the network of Capillary vessels which traverses the most vascular. In both cases, the nutrient materials conveyed by the blood are absorbed by the cells or other elementary parts of the tissue immediately adjoining the vessels, and are imparted by them to others which are further removed; and the only difference lies in the amount of the portion of tissue which has to be thus traversed; so that we are merely required to extend our ideas from the largest of the islets which we find in the vascular tissues, to the still more isolated structures of which the non-vascular tissues are composed. The disposition of the Capillaries, as to both the plan and the degree of minuteness of the reticulation they form, varies so greatly in the different parts of the fabric, that it is possible to state with tolerable certainty the nature of the part from which any specimen has been detached,—whether a portion of Skin (Fig. 46), Mucous membrane (Figs. 36, 37), Serous membrane, Muscle (Fig. 104), Nerve (Fig. 110), Fat (Fig. 32), Connective tissue, Gland (Fig. 44), &c. But the arrangement of vessels peculiar to each evidently has reference only to the convenience of the distribution of blood among the elementary parts of the tissue, and varies with their form. It cannot have any other relation than this to their function; since the function of each separate element of the organ, of which that of the entire organ is the aggregate, is due to its own inherent vital powers,—the supply of blood being only required as furnishing the material on which these are to be exercised.

321. It seems pretty certain that the Capillaries of Animals, like the straight and anastomosing Ducts of Plants, are formed by the coalescence of cells. Bodies having the appearance of cell-nuclei may frequently be seen in the walls of the capillaries of Embryos and of Tadpoles; and these are too wide apart to warrant the idea that they are the nuclei of epithelial cells, such as line the larger vessels. Similar nuclei may be brought into view in the capillaries of adult animals, by treating them with acetic acid; and they are particularly well seen in the Pia Mater, which consists almost entirely of a congeries of blood-vessels (Fig. 94). The accompanying figure shows the contrast between the long oval nuclei *b*, *b*, imbedded at intervals in the

walls of the true capillaries, and rather projecting on their exterior; and the nuclei of the epithelium-cells, *f, f*, lining the interior of a larger branch, which last are more numerous and of less regular form, and are sometimes placed transversely to the direction of the tube.—The inference suggested by the presence

Fig. 94.*



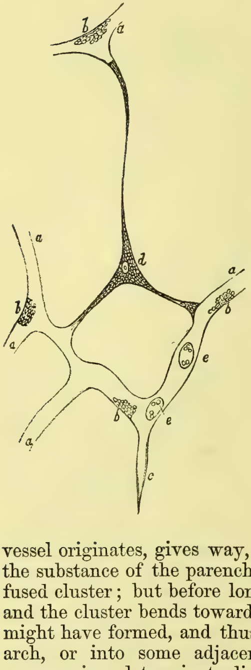
of these nuclei is confirmed by observation of the development of the Capillary vessels, which has been specially studied by Prof. Kölliker in the tail of the very young Tadpole. The first lateral vessels of this organ have the form of simple arches passing between the main artery and vein, and are produced by the junction of prolongations shot forth from these vessels, with similar prolongations from stellate or caudate cells in the substance of the tail (Fig. 95). Some of the latter, again, coalesce with those of other cells; so that an irregular network is produced, which communicates with the previously-formed trunks. The cavities of these cells and of their radiations (which are at first so fine as to be almost impervious) having coalesced, they begin to receive fluid from the vessels, then enlarge, and finally appear as continuations of them.—So in the fine gelatinous tissue conveying the umbilical vessels of the embryo-sheep to the uterine cotyledons, there may be seen chains and networks of cells of various shapes, some fusiform, some stellate, some round or oval with thread-like prolongations, connected to each other and to the

* Capillary Blood-vessels from Pia Mater:—*a*, calibre of the tube, partly occupied by oval nuclei, alternately arranged lengthways, and epithelial in their character; *b, b, b*, nuclei projecting on the exterior of the tube; *c, c*, walls, and *d*, calibre, of a large branch; *f, f*, oval nuclei, arranged transversely.

adjacent blood-vessels by slender prolongations, which gradually enlarge, and become filled with blood from the vessels with which they come into communication.

322. In the production of new parts for the repair of injuries, the tissue ordinarily becomes supplied with blood-vessels by outgrowth from the capillaries of the subjacent structure. "The vessel," according to the description of Mr. Paget, "will first present a slight dilatation in one, and coincidently, or shortly after, in another point; as if its walls yielded a little near the edge or surface. The slight pouches thus formed gradually extend, as fluid canals or diverticula, from the original vessel; still directing their course towards the edge or surface of the new material, and crowded with corpuscles, which are pushed into them from the main stream. Still extending, they converge; they meet; the partition-wall that is at first formed by the meeting of their closed ends, clears away, and a perfect arched tube is formed; through which the blood, diverging from the main or former stream, and then rejoining it, may be continuously propelled." Sometimes the projecting pouch in which the new vessel originates, gives way, and the blood-corpuscles escape into the substance of the parenchyma; at first they lie there in a confused cluster; but before long they manifest a definite direction, and the cluster bends towards the line in which the new vessel might have formed, and thus opens into the other portion of the arch, or into some adjacent vessel. This formation of new passages in a determinate direction by a process of 'channelling,' indicates the existence or forces in the parenchyma itself, that determine the direction in which the vessels shall prolong them-

Fig. 95*.



* Formation of Capillaries in tail of Tadpole :—*a*, *a*, capillaries permeable to blood; *b*, *b*, cell-nuclei with remains of contents of primitive formative cells; *c*, hollow prolongation of a capillary ending in a point; *d*, a branching cell, with nucleus and granules, communicating by three branches with capillaries already formed; *e*, blood-corpuscles, still containing granules.

selves when the new passage is formed by their outgrowth; in fact it would not seem improbable that this outgrowth is itself but a sort of varicose dilatation, consequent upon the breaking down of the tissue into which it extends itself.

323. There is good ground to believe, however, that (as John Hunter long ago maintained) an independent formation not merely of Blood-vessels but of Blood may take place in 'false membranes' or in tissues produced for the repair of losses of substance, as in the 'Vascular Area' of the embryo (§ 549). The first network of vessels seen therein, though often designated as a 'capillary' reticulation, is not so in reality; its tubes being formed, not by the meeting of stellate prolongations put-forth from cells originally wide apart, but by the coalescence of the cavities of rows of cells that are compacted into solid cords; the axial cells of these cords being metamorphosed into blood-corpuscles, whilst the cells which surround them are converted into the tissues that form the walls of the vessels. This is the mode, too, in which the Heart and the principal Blood-vessels of the embryo originate; their earliest condition being that of solid cellular cords of greater or less thickness, the interior portions of which subsequently undergo diffluence, with a metamorphosis of their central cells into Blood-discs, whilst the exterior are developed into the fibrous and other tissues of the walls of these cavities. Pulsations have been observed in the embryonic heart, whilst it is still in the cellular condition.

324. The structure of the minutest *Absorbent* vessels is very similar to that of the capillary Blood-vessels. Both in the substance of the tissues in which the *lymphatics* take their origin, and in the extremities of the intestinal villi in which are the radicles of the *lacteals*, they seem to originate in plexuses; which, however, are unlike those of the capillary blood-vessels, in communicating with trunks on one side only. These plexuses are formed, according to the observations of Prof. Kölliker, on the same original plan with those of blood-vessels; namely, by the junction and fusion of processes from stellate cells either with each other, or with off-shoots from previously-existing vessels. In the development or the lymphatic tubuli, however, the union of the cells is in a more simple linear direction than it is in the production of capillaries; the anastomosis of the former, in their complete state, being much more rare that that of the latter.

7. *Of the Muscular and Nervous Tissues.*

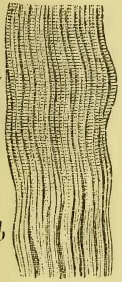
325. We now come to two tissues of the highest importance in the Animal fabric; the presence of which, indeed, is its distinguishing characteristic. These are the *Muscular* and the *Nervous* tissues. The former is the one by which all the sensible

movements of the body are effected; whilst the latter furnishes the instrument by which *sensations* are received, and by which the *will* excites the muscles to action, besides serving as the medium for other operations in which motion is produced without the intervention of either sensation or will. These tissues, with the apparatus of bones and joints on which the muscles act, constitute the purely *animal* portion of the fabric; and if a being could be constructed in which they should be capable of continued activity without any other assistance, it would be in all essential particulars an Animal. But it is an essential condition of the continued exercise of the powers of these tissues, that they should be constantly in receipt of a fresh supply of aerated blood, and should be enabled to get rid, through the circulating current, of the products of the *waste* consequent upon their action; so that the Animal cannot exist without an apparatus for preparing, circulating, and maintaining in constant purity the fluid which is to furnish both the materials for the nutrition of these tissues and the oxygen whose presence enables them to exert their energy. This apparatus constitutes the Vegetative portion of the frame, the component elementary parts of which have been already noticed.

326. When we examine an ordinary Muscle with the naked eye, we observe that it is made-up of a number of *fasciculi* or bundles of fibres, arranged side by side with great regularity, in the direction in which the muscle is to act, and united by Connective tissue. These fasciculi may be separated into smaller parts which appear like simple fibres; but when these are examined by the microscope, they are found to be themselves fasciculi, composed of minuter fibres bound-together by delicate filaments of Connective tissue. By carefully separating these, we may obtain the ultimate *Muscular Fibre.* This fibre exists under two forms, the *striated* and the *non-striated:* the former, characterized by transverse striations repeated at regular intervals (Fig. 96), makes-up the whole substance of those muscles over which the will has control, or which are usually called into operation through the nerves; whilst the latter (Fig. 101) takes its place in most of the muscles which the will cannot influence, and which are ordinarily excited to contraction by stimuli that act *directly* upon them. The muscles of the former class minister especially to the *animal* functions; those of the latter to the functions of *organic* or *vegetative* life. There is a marked exception, however, in the case of the Heart; which, although belonging to the apparatus of Organic life, is composed of striated fibre. On the whole, it would seem more correct to say that the Striated fibre is employed wherever muscles are required to contract with rapidity and consentaneous energy; whilst the Smooth or Non-striated fibre is found in muscles which are destined to execute slower and more

gradual movements. And this statement accords well with the fact that the muscles of *Articulated* animals, whose general character is activity, are ordinarily composed of striated fibre; whilst those of *Mollusca*, whose general character is *sluggishness*, are nearly always composed of non-striated fibre,—the most marked exception being in the muscles of *Terebratula* and its allies, which are strongly striated (Fig. 98).

Fig. 96*



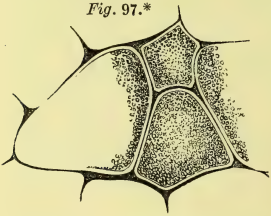
327. When the Striated fibre, which must be considered as the highest form of Muscular tissue, is more closely examined, it is seen to consist of a delicate tubular sheath, quite distinct on the one hand from the connective tissue which binds the fibres into fasciculi, and equally distinct from the internal substance of the fibre. This tube, on account of its transparency, cannot always be brought into view; it becomes most evident when (as occasionally happens) the contents of the fibre are separated transversely by the drawing-apart of its extremities, without the rupture of the sheath; but it may also be sometimes seen rising up in wrinkles upon the surface of the fibre, when the latter is in a state of contraction. The tubular sheath, which is termed the *Sarcolemma*, has nothing to do with the production of the striæ; these being due, as will be presently shown, to the peculiar arrangement of its contents. It is not perforated by Capillary vessels; and although it has been recently asserted that the ultimate filaments of the motor Nerves find their way to its interior, there are good grounds for still doubting the validity of the observation. That it has no share in the contraction of the fibre, is evident from the fact just mentioned, in regard to its wrinkled aspect when the fibre is shortened.

328. Although Muscular Fibres are commonly described as cylindrical in form, yet they are in reality rather polygonal, their sides being flattened against those of the adjoining fibres (Fig. 97). In some instances, the angles are sharp and decided; in others they are rounded-off, so as to leave spaces between the contiguous fibres for the passage of vessels. In Insects, the fibres often present the form of flattened bands, on which the transverse striæ are very beautifully marked. The size of the fibres is subject to great variation, not merely in different classes of animals, but in different species, in different sexes of the same species, and even in different parts of the same muscle. Thus

* Fasciculus of striated Muscular Fibre, showing at *a* the transverse striæ, and at *b*, its junction with the Tendon.

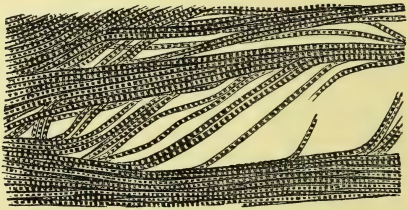
Mr. Bowman estimates the *average* diameter of the fibres in the Human *male* at 1-352nd of an inch, the *largest* being 1-192nd, and the *smallest* 1-507th. In the *female*, he found the *average* to be 1-454th of an inch, the largest being 1-384th, and the smallest 1-615th. The average size of the Muscular fibre is greater among Reptiles and Fishes than in other Vertebrata, and the extremes are also much wider; thus its dimensions vary in the Frog from 1-100th to 1-1000th of an inch, and in the Skate from 1-65th to 1-300th.

Fig. 97.*



329. When the Striated fibre is examined still more closely, it it is found to contain an assemblage of very minute particles of a nearly cylindrical though somewhat beaded form, and of very uniform size. These primitive particles are adherent to each other, both longitudinally and laterally. The former adhesion is usually the more powerful, causing the substance of the fibre when broken up to present itself in the form of delicate *fibrillæ*, each of which is composed of a single *row* of the primitive particles (Fig. 98). On the other hand, the lateral adhesion is sometimes the stronger; and causes the fibre to break across into *disks*, each of which is

Fig. 98.†



composed of a *layer* of the primitive particles (Fig. 99). The separation into fibrillæ is so much more easily made in many of the lower animals, than it is in Man and the higher animals, as to afford ground for the belief that the fibrillæ of the latter are held together by some intermediate substance.

* Transverse section of Striated Muscular fibre, showing the polygonal form of the fibres, and their composition of ultimate fibrils.

† Striated Muscular Fibre separating into Fibrillæ (from Terebratula).

330. When the fibrillæ are separately examined under a high magnifying power, they are seen to present the same alternation of light and dark spaces, as when united into fibres or into small bundles; but it may sometimes be distinctly seen† that each light space is divided by a transverse line, and that there is a pellucid border at the *sides* of the dark spaces, as well as between their contiguous extremities (Fig. 101). This pellucid border would seem to be a cell-wall, and the dark space enclosed by it (which is usually bright in the centre) to be the cavity of the cell, which is filled with a highly-refracting substance. When the fibril is in a state of relaxation, as seen at *a*, the diameter of its component cells is greatest in the longitudinal direction; but when it is contracted, the fibril increases in diameter as it diminishes in length, so that the transverse diameter becomes equal to the longitudinal diameter, as seen at *b*, or even exceeds it. If this be a correct account, the act of Muscular contraction would seem to consist in a change of form in the cells of the ultimate fibrillæ, consequent upon an attraction between the walls of their two extremities; and it is interesting to observe, how very closely it thus corresponds with the contraction of certain Vegetable tissues, of which the component cells (§ 339) appear to produce a movement when they are irritated, by means of a similar change of form. The essential difference, therefore, between the muscular tissue of Animals, and the contractile tissues of Plants, consists in the subjection of the former to nervous influence (§ 347). The diameter of the ultimate fibrillæ will of course be subject to variations, in accord-

Fig. 99.*

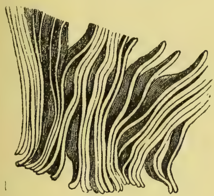
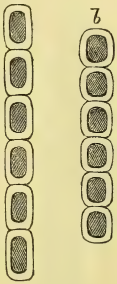


Fig. 100.‡



* An ultimate Fibre, in which the transverse splitting into Disks, in the direction of the striation of the ultimate fibrils, is seen.

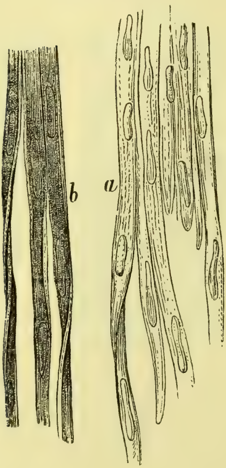
† This account of the ultimate structure of the fibrillæ of Striated muscular fibre was originally published contemporaneously and independently by Dr. Sharpey and by the Author, as the result of their observations on the preparations of the muscular fibre of the Pig made by Mr. Lealand. And the Author has still sufficient confidence in them to repeat them here, notwithstanding the high authority of Prof. Kölliker, who considers that "our microscopes do not afford adequate data for forming a sure judgment respecting elements of such fineness."

‡ Structure of the ultimate Fibrillæ of Striated Muscular fibre:—*a*, a fibril in a state of ordinary relaxation; *b*, a fibril in a state of partial contraction.

ance with their contracted or relaxed condition; but it seems to be otherwise tolerably uniform in different animals, being for the most part about 1-10,000th of an inch. It has been observed, however, as high as 1-5000th of an inch, and as low as 1-20,000th, even when not put upon the stretch. The average distance of the striæ, too, is nearly uniform in different animals; though considerable variations present themselves in every individual, and in different parts of the same muscle. Thus the minimum distance varies in different animals from 1-15,000th to 1-20,000th of an inch; the maximum from 1-7500th to 1-4500th of an inch; while the mean does not depart widely in any instance from 1-10,000th.

331. The Smooth or Non-striated form of Muscular tissue seldom presents itself among the higher animals in the form of large isolated muscles; but occurs either scattered through Connective tissue, or in plexuses interwoven together to form muscular membranes. The appearance which its fibres present, when separated by mechanical means alone, is that of flattened bands whose diameter is usually between 1-2000th and 1-3000th of an inch (Fig. 101); the substance of these is translucent, but sometimes finely-granular; nothing like a sarcolemma can be distinguished; but they are usually marked at intervals by peculiar elongated nuclei, which, when not originally visible, may be rendered so by acetic acid, and which often project so as to form nodosities upon the fibre. When these bands are collected into fasciculi, the fibres generally lie parallel to each other; but the fasciculi themselves often cross each other and interlace. They have not, as a general rule, fixed points of attachment like the fasciculi of striated muscles; but usually form continuous investments round cavities lined by mucous membranes. It is of this kind of structure that the proper muscular coat of the œsophagus, of the stomach and intestinal canal, and of the gall-bladder and urinary bladder, is essentially composed. A similar but more delicate muscular layer surrounds the trachea

Fig. 101.*

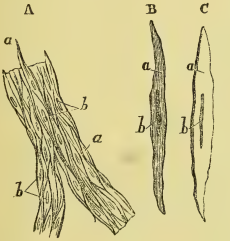


* Non-striated Muscular Fibre: at *b*, in its natural state; at *a*, showing the nuclei after the action of acetic acid.

and bronchi as far as their finest subdivisions, the principal gland-ducts, the vasa deferentia, and the Fallopian tubes; and it is to this form of muscular substance, developed to an extraordinary degree during pregnancy, that the Uterus owes its contractile power. Non-striated Muscular fibres and fasciculi are also found, blended with various forms of the simple Fibrous tissues, in Erectile structures, and also in the Skin (§ 244). The larger Arteries also possess a distinct muscular envelope composed of the same form of tissue; and although in the smaller blood-vessels no fibres can be recognized, yet, as will be presently shown, the essential constituents of non-striated muscle are not wanting in them.

332. The so-called fibres of Non-striated Muscle have been shown by Prof. Kölliker to be resolvable, after maceration in dilute nitric acid, into fasciculi of cells, which are usually more or less elongated. These are composed of a soft, light-yellow substance, which swells in water and acetic acid, becoming pale in the latter, and which is nearly homogeneous, so that it is difficult to distinguish the cell-wall clearly from the cell-contents; but they are especially characterized by the possession of long staff-like nuclei (Fig. 102, *b*, *b*), which are sometimes only rendered perceptible by acetic acid. These cells are sometimes so little elongated, especially in the walls of the blood-vessels, that they might be taken for epithelial cells if it were not for their peculiar nuclei; but they are commonly more or less fusiform (Fig. 102, B), and are then arranged in the manner shown at A, several such cells being closely united by lateral adhesion in what seems to be a single fibre. In the smaller Arteries, however, the form of the cells is much less elongated; and they sometimes come to bear a close resemblance in shape to epithelium-cells, from which, however, they are distinguished by the peculiar form of their nuclei. The Muscular structure of the Heart is peculiar in combining the general arrangement of the non-striated muscles, as regards the interlacement of the fasciculi and the absence of fixed points of attachment, with the ultimate structure of the striated. The fibres are of smaller diameter, however, than those of the ordinary muscles, and the striæ are less

Fig. 102.*

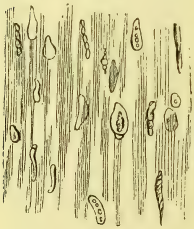


* Component fusiform cells of Non-striated Muscular fibre:—A, trabecula of spleen, with the cells *in situ;* B, a single cell isolated; C, a similar cell treated with acetic acid;—*a*, *a*, cells; *b*, *b*, nuclei.

strongly marked and less regular. In the heart, too, is seen more frequently than elsewhere the subdivision and anastomosis of the fibres themselves.—No proper gradation can be anywhere traced between the striated and non-striated forms of Muscular tissue; but the two sometimes come into very close apposition, as where the constrictors of the pharynx overlie the proper muscular coat of the œsophagus.*

333. It was formerly supposed that each Muscular fibre of the Striated kind takes its origin, like the straight ducts of Plants, in cells laid end-to-end, forming a tube by their coalescence; within which tube—the Sarcolemma—the rows of fibrillæ are subsequently developed. The later researches of Prof. Kölliker, however, lead him to regard each fully-formed fibre as a single cell, the early condition of which in the Striated muscles closely corresponds with the state just shown to be persistent in the fibres of the Non-striated. The change which subsequently takes place consists in the elongation of the cell, in the multiplication of its nucleus by subdivision and the separation of secondary nuclei thus produced, and in the metamorphosis of the cell-contents into fibrillæ, the original cell-wall remaining as the sarcolemma.† The nuclei of embryonic muscular fibre are very conspicuous, and are often seen to raise the sarcolemma into rounded elevations. They may be readily distinguished at the conclusion of fœtal life; and the presence of some may generally be traced even in the muscular fibre of the adult by treating it with some weak acid, the effect of which is to render the nuclei more opaque whilst the surrounding structure becomes more transparent (Fig. 103). They are usually numerous in proportion to the size of the fibre.—The diameter of the Muscular Fibre of the fœtus is very small in comparison with that which it possesses in the adult; and as the *size* of the ultimate particles is the same in both cases, their *number* must be greatly multiplied during the growth of the structure.

Fig 103 ‡



334. Muscles are usually connected at one or both extremities

* It is curious that the parasitic *Trichina spiralis* infests only the striped muscles.

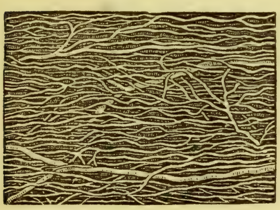
† See Prof. Kölliker's "Manual of Human Anatomy," p. 185; also a Memoir by Mr. J. Lockhart Clarke "On the Development of Striped Muscular Fibre" in "Quart. Journ. of Micr. Science," Vol. II. N. S., p. 222, Vol. III., p. 1.

‡ Mass of Muscular fibres from the pectoralis major of the human fœtus at nine months. These fibres haxe been immersed in a solution of tartaric acid; and their numerous corpuscles, turned in various directions, some presenting nucleoli, are shown.

with Tendons; and when the direction of the tendinous fibres is the same as that of the Muscular, there seems to be a gradational transition from the one form of structure to the other (Fig. 96, *b*). This, however, is probably not the case; for where a muscle and a tendon unite obliquely (as in the 'penniform' muscles), and still better where a muscle passes by a very thin edge into an aponeurotic expansion (as is well shown in the abdominal muscles of the Frog), the muscular fibres can be distinctly seen to terminate by rounded tapering extremities, which are received into hollows of the tendinous structure; and it can scarcely be doubted that the fibrous tissue of the Tendon is continuous with the Connective tissue that surrounds and unites together the Muscular fibres, rather than with those fibres themselves. The same kind of continuity exists between the fibres of the Muscular Connective tissue and the fibres of Periosteum or Perichondrium, when (as sometimes happens) Muscles are attached to Bone or Cartilage without the intermediation of Tendon; and it may be traced also with the Connective tissue of Skin, in the case of certain muscles whose action is on the integuments or its appendages.

335. We have seen that the Muscular tissue properly so called, is as extra-vascular as cartilage or dentine; for since its fibres are not penetrated by vessels, the nutriment required for the growth of their contained matter must be drawn by absorption through the sarcolemma. But the substance of Muscle is extremely vascular; the capillary vessels being distributed in nearly parallel lines, in the minute interspaces between the fibres (Fig. 104); so that there is probably no fibre which is not in close relation with a capillary. Hence there is every provision for the active nutrition of this tissue; the arterial circulation bringing the materials for its growth and renovation; whilst the venous conveys away the products of that waste or disintegration which is consequent upon its active exercise.—The supply of blood is not merely requisite for the *nutrition* of the muscular tissue; it also affords a condition which is requisite for its *action*. This condition is the presence of Oxygen. It is not enough that blood should circulate through the muscles; for that blood, to exercise any beneficial influence, must be arterialized. Consequently the muscles of warm-blooded animals soon lose their contractile power, after the supply of arterial blood has been

Fig. 104.*

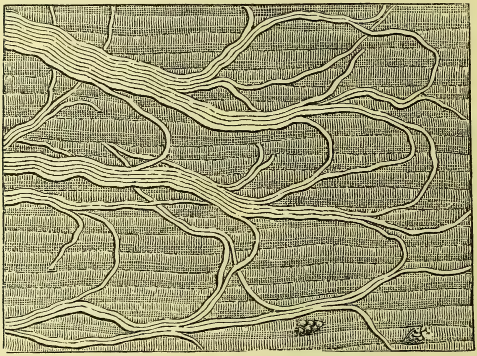


* Capillary network of Muscle.

suspended, either by the cessation of the circulation, or by the want of aeration of the blood; but those of cold-blooded animals preserve their properties for a much longer period, in accordance with the general principle formerly stated,—that, the lower the usual amount of vital energy, the longer is its persistence after the withdrawal of the conditions on which it is dependent.

336. The Muscles of Animal Life are, of all the tissues except the Skin, the most copiously supplied with Nerves. These, like the blood-vessels, lie on the *outside* of the Sarcolemma of each fibre; and their influence must consequently be exerted through it. The general arrangement of these nerves is shown in the succeeding figure. The fibres into which the trunks subdivide form a series of loops, which for the most part either return to the same trunk, or join an adjacent one (Fig. 104). The occasional appearance of a termination to a nervous fibril is often

Fig. 104.*



caused by its dipping down between the muscular fibres, to pass towards another stratum; but it appears from recent inquiries to be sometimes due to a subdivision of the central axis into a brush-like group of minute fibrils, which either at last terminate in free extremities, as affirmed by Prof. Kölliker, or return upon themselves in looped plexuses resembling those of the larger fibres, as appears from Prof. Beale's researches.† The Non-striated muscles, however, are very sparingly supplied with nerves; and these are derived (for the most part, if not entirely) from the Sympathetic system in the first instance, rather than from the Cerebro-spinal.

* Portion of Muscle, showing the general arrangement of the Motor Nerves supplying it.

† See his Memoirs on this subject in the "Philos. Transact." for 1860, 1862.

337. Notwithstanding the energy of growth in Muscular tissue, it is doubtful if its Striated form is ever regenerated, when there has been actual loss of substance. Wounds of Muscles are united by Connective tissue, which gradually becomes condensed; but its fibres never acquire any degree of contractility. We have in the pregnant Uterus, however, a remarkable case of rapid production of the Non-striated muscular substance; the extraordinary development of this substance during pregnancy being partly due to the increase in size of the fibre-cells previously existing, and in part to the development of new fibre-cells.

338. Muscular fibre has usually been regarded as identical in ultimate composition with the Fibrin of the blood; but, as already stated (§ 184), the two substances Syntonin and Fibrin differ in chemical properties. The muscle-substance of veal, however, bears a closer resemblance to the fibrin of blood, than to that of adult muscle.—The ordinary substance of Muscle contains about 75 per cent. of water; and of the 25 parts of solid matter, about 17 consist of the true muscle-substance, the remainder being made up of gelatigenous tissues, fat, saline matters, and extractive. This last is a general term, including several products of retrograde metamorphosis, which are especially found in muscles that have been subjected to great exercise; such as free lactic acid (giving to the juice of flesh an acid reaction), the neutral substances kreatin and kreatinin (§ 735), inosite or muscle-sugar (§ 175), and the salts of lactic, acetic, butyric, and formic acids.

339. We now come to investigate the remarkable property which is the distinguishing characteristic of Muscular tissue;—that of contracting on the application of a stimulus. Some approaches to this property are manifested by certain Vegetable structures. Thus, if the small enlargement at the base of the footstalk of the leaf of the Sensitive Plant be touched ever so slightly, the leaf will be immediately drawn-down by the contraction of the tissue of the part irritated. If the leaf itself be touched, the same effect results, but apparently through a different channel; the tissue of the leaf contracts where it is touched, and forces some of its fluid along the vessels of the footstalk into the upper side of the little excrescence at its base, by the distension of which the leaf is forced down. In the *Dionæa muscipula*, or Venus's Fly-trap, there is a similar transmission of the effect of the stimulus from one part to another; for the two lobes of the leaf which form the trap are made to close together when an insect settles upon either one of three spines which project from the surface of each lobe, or when the points of these spines are touched with any hard body.—Many other instances of Vegetable movement might be brought together. Some of them are obviously produced by an enlargement or contraction of the cells, occasioned by variations in the amount of fluid they contain; and these

variations depend upon the hygrometric state of the atmosphere. With these we have nothing to do. But there are many in which (as in the case of the Sensitive Plant first mentioned) a stimulus applied to a part occasions the immediate contraction of its cells, and a consequent motion in the *same* part. And there are also several in which the contraction produces motion in a *distant* part, as in the Dionæa; but this propagation appears to be of a simply mechanical character; being accomplished through the medium of fluid, which is forced from one part by its own contraction, and caused to distend another.

340. From these examples, however, it is evident that the property of Contractility is not entirely restricted to the Animal kingdom; and we shall find that the simplest form under which it manifests itself in the Animal body, bears a close relationship with that which is displayed in Plants. The Non-striated fibre of the alimentary canal, which is subservient to the functions of Vegetative life alone, is called into action much more readily by a stimulus directly applied to itself, than it is in any other mode. Such is not the case, however, with the Striated fibre of which the muscles of Animal life are composed; this being much more readily called into action by the peculiar stimulus conveyed through the Nerves supplying those muscles, than by any other that may be more directly applied to them.

341. The Contractility of Muscular fibre shows itself under two forms. Its ordinary manifestations are those that occur in the Voluntary muscles and in the Heart; which, when in activity, exhibit powerful contractions alternating with relaxations. Even when a continuous contraction is maintained for some time in a Voluntary muscle by a strong effort of the Will, there is reason to believe than an alternation of contraction and relaxation takes place among the individual fibres; only a part of them being in a state of contraction at any one time (§ 350). But Muscular fibre is also liable to be thrown into a state of persistent and rigid contraction, which is not disposed to give place readily to relaxation; of this we have examples in the Tetanic spasm of Voluntary muscles, in the spasm of the Heart which is an occasional cause of sudden death, and also in that contraction of the smaller Arteries, which (there seems good reason to believe, § 583) is a frequent cause of disordered function. This *tetanized* condition of Muscular fibre may be artificially induced (§ 352).

342. That the Contractility of Muscles is a property inherent in themselves, and is in this respect analogous to the peculiar vital endowments of other forms of tissue, cannot, in the Author's opinion, be reasonably doubted; though some Physiologists have sought to show that it is in some way derived from the Nerves. Not only may an entire Muscle be made to contract, by the application of a proper stimulus, long after the division of the

nervous trunks supplying it; but even a single fibre, completely isolated from all its nervous connections, may be seen to contract under the Microscope. Moreover, it is often difficult to excite contractions in Non-striated muscle through the nerves at all, when a stimulus directly applied to itself will immediately produce sensible and vigorous movements. The energy of the contractile power depends in great part upon the state of nutrition of the muscle; and this again is influenced by the degree in which it is exercised. Now as the Muscles of Animal Life are all excited to action, in the usual state of things, through the medium of their Nerves, it follows that if the nerves be paralysed, the muscles will be seldom or never called into use. When disused they will receive very little nourishment; the disintegrating changes will not be counterbalanced by reparative processes; and in consequence, the muscular structure will be gradually so far impaired as to lose its peculiar properties, and will even in time almost totally disappear. Yet, even after the almost complete departure of muscular contractility, through the metamorphosis of the structure consequent upon disuse, it may be again recovered if the muscles be called into exercise; but the recovery of the power is very slow, and proceeds *pari passu* with the improvement in the nutrition of the part, being more tedious in proportion to the length of the previous disuse.

343. That the Contractility of Muscular fibre belongs to itself, and is not derived in any way from the nerves, is further shown in the following manner:—If a set of muscles (as those of the leg of a Rabbit or Frog) be repeatedly thrown into action by galvanism, until the stimulus no longer occasions their contraction, their irritability is then said to be exhausted; by rest, however, it is recovered,—the nutritive process making-good the loss previously suffered. Now it has been shown by Dr. J. Reid, that this recovery may take place even after the division of all the nerves supplying the limb, provided that the nutrition of the part be not interfered with; and it was further shown by the same excellent Physiologist, that if the nerves of a limb be divided, the loss or retention of the contractility of the muscles entirely depends upon the degree of exercise to which they are subjected, and consequently upon the nutrition they receive. The muscles of the hind-leg of a Rabbit whose sciatic nerve had been divided, were found to have almost completely lost their contractility in the course of seven weeks; they were much smaller, paler, and softer, than the corresponding muscles of the opposite leg; and they scarcely weighed more than half as much as the latter. Now when the nerves of *both* hind-legs of a Frog were cut, and the muscles of *one* of the limbs thus paralysed were daily exercised by a weak galvanic battery, while those of the other were allowed to remain at rest, it was found, after the lapse of two

months, that the muscles of the exercised limb retained their original size and firmness, and contracted vigorously, whilst those of the other had shrunk to one-half their former size. Though the latter still retained their contractility, there could be no doubt that they would soon lose it, by the progress of the change already far advanced in their physical structure; this change not being as rapid in cold-blooded animals, as in Birds and Mammals.

344. By these and other facts (§ 358), then, it may be regarded as completely proved that the Contractility of Muscles is a vital endowment, belonging to them in virtue of their peculiar structure; that so long as this structure is maintained in its normal condition by the nutritive processes, so long is the property capable of being manifested;—but that any cause which interferes with the nutrition of a muscle, impairs or destroys its contractility. No cause is so effectual in doing this as complete *disuse;* and no means is so sure to produce complete disuse of a muscle as the division of its nerve, since its being called into exercise in any other way is very improbable; hence the section of the nerve is almost certain to produce, in time, the loss of the contractility of the muscle. But if a means be devised by which the muscle may still be called into action in any other way,—as in Dr. Reid's experiment just quoted,—its contractility is retained because its regular nutrition is kept-up.

345. All Muscular Fibre which has not lost its contractility, may be made to contract by a stimulus applied *directly to itself;* and this stimulus may be of different kinds. The simplest is the contact of a solid substance; thus we may excite muscular contraction by simply touching the fibre, just as we cause contraction in the tissue of the Dionæa or Sensitive Plant. Most substances of strong Chemical action, such as acids and alkalies, will call forth the contractility of muscular fibre, when applied to it; and the same result is produced by Heat, Cold, and Electricity,—the last-named agent being the most powerful of all (§ 352).

346. The effect of the application of any of these stimuli varies considerably, according to the kind of Muscle on which it is exerted. If we irritate a portion of a muscle composed of *striated* fibre (any one of the Voluntary muscles for example), the fasciculus of fibres which is touched will immediately contract, and that one only; and the contracted fasciculus will soon relax, without communicating its movement to any other. If we irritate a portion of *non-striated* fibre, however, as that of the Alimentary canal, the fasciculus which is stimulated will contract less suddenly, but ultimately to a greater amount; its relaxation will be less speedy; and before this takes place, other fasciculi in the neighbourhood begin to contract, their contraction propagates itself to others; and so on. In this manner successive contractions and relaxations may be produced through a considerable

part of the canal by a single prick with a scalpel; a sort of wave of contraction being transmitted in the direction of its length, and being followed by relaxation. In the Muscular structure of the Bladder and Uterus, again, powerful contractions are excited by irritation, and these produce a great degree of shortening; but they do not alternate in the healthy state with any rapid and decided elongation; whilst, on the other hand, an irritation applied to one spot causes more extensive contractions than are seen to occur as its immediate consequence in the preceding cases. In the Heart, the muscular structure of a large part of the organ is thrown into rapid and energetic contraction by a stimulus applied at any one point; and this contraction is speedily followed by relaxation. And in the fibrous tissue of the middle coat of the Arteries, the contraction takes-place rather after the manner of that of the bladder and uterus, and a prolonged application of the stimulus is often necessary to produce the effect; but when the contraction commences it produces a considerable degree of shortening, which takes-place in other fasciculi than those directly irritated, and does not speedily give way to relaxation.

347. On the other hand, when the stimuli which excite muscular contraction are applied *to the nerve* which supplies a Voluntary muscle composed of Striated fibre, they produce a simultaneous contraction in the whole muscle; the effect of the stimulus being at once exerted upon every part of it. In the ordinary action of such muscles, the nervous system is always the channel through which they are called into play, whether to carry into effect the determinations of the mind (§ 390), or to perform some office necessary to the continuance of life, such as the movements concerned in Respiration (§ 393): and the stimulus to their contraction really has its origin in some remote part, the Cerebro-Spinal system serving as the medium of its transmission.—The ordinary actions of Non-striated muscles, on the contrary, are executed in respondence to stimuli applied directly to themselves; and although recent investigations have shown that numerous minute ganglia are dispersed through their substance, to the reflex agency of which some Physiologists are disposed to refer their ordinary contraction, yet there appear to the Author to be valid reasons for not accepting this view. It is so difficult to excite contractions in muscles of this class through the medium of their nerves, that many have denied the possibility of doing so; and the nerves lose their power of conveying the influence of stimuli very soon after death, although the contractility of the muscles may remain for a considerable time longer.

348. When a Muscle is thrown into contraction, its bulk does not appear to be at all affected. Its extremities approach, so that it is shortened in the direction of its fibres; but its diameter enlarges in the same proportion. It was formerly supposed that the ulti-

mate fibres, in the act of contraction, threw themselves into zigzag folds; but this is now well-ascertained not to be the case. The fibre, like the entire muscle, preserves its straight direction in shortening, and increases in diameter. The fibrillæ themselves, as already mentioned (§ 330), exhibit an evident change in regard to the distances of their successive light and dark portions; and the fibre which is made-up of these, exhibits in its contracted state such a close approximation of the transverse striæ, that they become two, three, or even four times as numerous in a given length, as they are in a similar length of non-contracted fibre. According to Mr. Bowman's observations, the contraction usually commences at the extremities of a fibre; but it may occur also at one or more intermediate points. The first appearance of contraction is a dark spot, caused by the approximation of the striæ; and this gradually extends itself, so as to involve a greater or less proportion of the length of the fibre. The approximation of the solid portions forces out the fluid which was previously contained amongst the fibrillæ; and this is seen to lie in bullæ or blebs beneath the sarcolemma, which is drawn-up into wrinkles.

349. The successive stages of the act of contraction can only be thus observed when it takes place very slowly, as in the *rigor mortis* or slow contraction after death, the phenomena of which will be presently noticed (§ 368). But the resulting change in muscular fibres which have been made to contract by galvanism or any other stimulus, is essentially the same. This may be best seen in transparent Entozoa, Crustacea, and others among the lower Articulated animals, whilst alive. Again, in persons who have died from Tetanus, a considerable number of the fibres are found to have been ruptured by violent spasmodic action; the contractile force, called into existence by the powerful stimulation of the nerves, having overcome the tenacity of the fibre: and in such cases, the same approximation of the transverse striæ, and proportional increase in the diameter of the fibre, are to be observed.

350. It appears that even when considerable force of contraction is being exerted, the *whole* fibre is seldom or never in contraction at once; but that a continual interchange is taking-place amongst its different parts,—some of them passing from the contracted to the relaxed state, as shown by the separation of the transverse striæ,—whilst others are taking up the duty, and passing from the relaxed to the contracted condition, as shown by the approximation of the striæ. But it is not only among the different parts of the individual fibres, that this interchange seems to take-place. There is good reason to believe that when a muscle is kept in a contracted state by an effort of the Will for any length of time, only a part of its fibres are in contraction at any moment; but that a continual interchange of condition takes-place amongst them, some contracting whilst others are relaxing, so that the

entire muscle remains contracted, whilst the state of every individual fibre may have undergone a succession of alternations. When the ear is applied to a muscle in vigorous action, an exceedingly rapid faint silvery vibration is heard, which seems to be attributable to this constant movement in its substance.

351. Thus it appears that the prolongation of the contraction of a muscle through any length of time, is not opposed to the fact that, in the individual fibres, relaxation speedily follows contraction; but it is only a peculiar manifestation of it. The ordinary movements of the Heart exhibit a different manifestation; its fibres contracting simultaneously, and relaxing together, instead of alternating amongst themselves like those of a voluntary muscle.

352. When Muscles composed of Striated fibre are subjected to the magneto-galvanic apparatus, which transmits a rapid succession of slight Electric shocks, a state of rigid tetanic contraction is excited, which lasts as long as the stimulus is transmitted, and ceases when it is withdrawn. In Non-striated Muscles, on the other hand, the contraction is more slowly excited by the like stimulus, but continues for a time after it is withdrawn; this is well seen in the smaller Arteries, which may be made to contract by the magneto-galvanic apparatus until they become quite impervious to blood.—Contraction of a peculiarly persistent kind is occasioned both in striated and in non-striated Muscle by variations of Temperature. Thus the legs of a Frog dipped into water of 130° become 'tetanized'; on the other hand, in the operation of 'crimping' fish, it is the immersion of the body in cold water after the muscles have been divided, which, by calling forth this kind of contraction, increases the firmness of their substance. We have a remarkable example of the influence of temperature on the non-striated form of muscular tissue, in the contraction which takes place in the wall of an Artery of a warm-blooded animal, when it is cooled down by exposure to air for some time; this contraction being sometimes almost sufficient to obliterate its tube. The effect of cold in augmenting, and of warmth in relaxing, that 'tonic' or persistent contraction of the walls of the blood-vessels, which has an important influence on the flow of blood through them (§ 610), is another example of the same general fact.

353. It appears alike from experiments and from pathological observation, that there is a tendency to 'rhythmical' contraction and relaxation in various muscles which are usually subject to the Cerebro-spinal nervous system, even when they are completely withdrawn from its influence. This has been noticed by M. Brown-Séquard in the diaphragm, in the intercostals, and in some of the muscles of locomotion, both in animals recently dead, and in the limbs of living animals which had been completely paralysed by division of their nerves; and there seems ground for believing

that the trembling movements of the hands and head in old age, in certain forms of paralysis, and in habitual drunkards and smokers, have this origin. The most remarkable manifestations of this independent contraction, alternating with relaxation, in particular muscles, are those which have been witnessed after death from Cholera and Yellow Fever, sometimes in respondence to stimuli applied to the muscles themselves, but in other instances quite spontaneously, and giving rise to movements strongly resembling the ordinary actions of the living state.

354. We have now to consider the conditions which are requisite for the manifestation of Muscular Contractility. It has been already pointed-out how close is the dependence of the property upon the due *nutrition* of the tissue; but the property cannot be long exercised except under another condition, which is consequently of almost equal importance,—the circulation of *oxygenated blood* through the substance of the muscle. The length of time during which the contractility remains after the circulation has ceased, varies inversely to the activity of the respiration of the animal. In *cold*-blooded animals, the standard of whose respiration is low, the contractility remains for many hours after death, even in the voluntary muscles; and the muscles of organic life retain it with great tenacity. Thus the heart of a Frog will go on pulsating for many hours after its removal from the body; and the heart of a Sturgeon, which had been inflated with air and hung-up to dry, has been seen to continue beating, until the auricle had absolutely become so dry as to rustle during its movements. An exceedingly feeble Galvanic current is sufficient to excite the muscles of these animals to contraction; so that Matteucci, in his experiments upon Animal Electricity, has been accustomed to use the prepared hind-leg of a Frog as the best indicator of the passage of an electric current. Among *warm*-blooded animals, whose respiration is vastly more active, the duration of the irritability is proportionally abbreviated; and the muscles of Birds, whose respiration is peculiarly energetic, lose this property at an earlier period after the cessation of the circulation than do those of Mammals. It is interesting to remark that the muscles of *hybernating* warm-blooded Mammals are reduced for a time to the level of those of cold-blooded animals, their contractility being retained almost as long as that of the latter;—thus confirming the general principle already stated, as to the relation between the amount of respiration and the duration of the contractility.

355. From experiments on the bodies of executed criminals who were previously in good health, Nysten ascertained that, in the Human subject, the contractility of the several muscular structures, as tested by Galvanism, departs in the following time and order;—the left ventricle of the heart first; the intestinal

canal at the end of 45 or 55 minutes; the urinary bladder nearly at the same time; the right ventricle after the lapse of an hour; the œsophagus at the expiration of an hour and a half; the iris a quarter of an hour later; and lastly, the auricles of the heart, of which the right retains its power longest, having in one instance contracted $16\frac{1}{2}$ hours after death.

356. That the circulation of Arterial or oxygenated blood through the Muscles, is an essential condition of the continuance of their Contractility, appears from this,—that after the general death of the system, and even after the removal of the brain and spinal cord, the muscles will preserve their contractility, and the action of the heart itself will continue for a long time, provided that the circulation through the lungs be kept-up by artificial respiration, on the principles hereafter to be explained (§ 688). If, on the other hand, whilst the general circulation continues, the circulation through a particular muscular part be interrupted, that organ will lose its contractility earlier than usual; but the contractility of the muscles will return (if the suspension of the circulation has not been too contracted) on the restoration of the flow of oxygenated blood through them. The various experiments of Dr. Brown-Séquard have most conclusively established this general fact; the contractility having been thus restored in some instances even after the *rigor mortis* had begun to show itself (§ 368).

357. On the other hand, we find that the Contractility of Muscles is deadened by various toxic agents; among which Carbonic acid is one of the most powerful. Thus if blood charged with carbonic acid instead of with oxygen circulate through the muscles, their contractility is speedily impaired and may even be destroyed. This is best seen when animals are killed by being caused to breathe an atmosphere highly charged with carbonic acid; the contractility of their muscles departing as soon as they are dead. In fact, the destruction of the contractility of the heart, by the circulation of venous blood through its substance, is one of the immediate causes of death. A similar effect is produced by the respiration of other gases, which are either poisonous in themselves, or which prevent that interchange of carbonic acid and oxygen which ought to take-place in the lungs. On the other hand, when animals have been made to respire oxygen, and their blood has consequently been highly arterialized, the contractility of their muscles is retained for a longer time than usual.—Again, it is found that the injection of lactic acid into the substance of a muscle speedily lowers its contractility; and there is good reason to believe that the removal of this and other products of the disintegration of the Muscular substance occasioned by its exercise (§ 338) is a not less important duty of the Circulating current, than the supply of nutritive material and oxygen.

358. The study of the influence of various toxic agents upon

Muscle has a special interest from its bearing on the question of the *independence* of the Contractile power of this tissue (§ 344). Thus the Woorara poison has been found to paralyse the motor nerves, affecting their peripheral extremities in the first instance, without diminishing the irritability of the muscles. And the Nervous system may be rendered, by the inhalation of Ether, utterly incapable of conveying a galvanic stimulus to the muscles, which are yet readily thrown into contraction by the application of the same stimulus to themselves. On the other hand, the Upas poison and Cyanide of Potassium, when injected into the blood, primarily abolish the contractile power of the Muscles themselves.

359. The peculiar vital power of Muscles, as of other parts of the organism, seems to be capable of sudden diminution, or even of annihilation, by violent impressions communicated through the Nervous system; as is seen in the effect of concussion of the brain, extensive burns of the surface, blows on the epigastrium, rupture of important viscera, or other kinds of *Shock*, in producing a general depression of muscular power, which is especially manifested in the failure of the Heart's action.

360. The Muscles, as we have seen, are largely supplied with blood; and the flow of blood into them increases with the use that is made of them. The demand for nutrition is obviously augmented in proportion to the activity of the exercise of the Muscular system; for the slightest observation suffices to show that a much smaller amount of nourishment is sufficient to sustain the body in its normal condition when the Muscular system is not actively exercised, than when it is in energetic operation. The quantity which is ample for an individual leading an inactive life, is far too little for the same person in the full exercise of his muscular powers. The permanently-increased flow of blood to a muscle, which takes-place when it is continually being called into vigorous action, is on the one hand occasioned by the demand for oxygenated blood created by its use, whilst on the other hand it tends to increase the power of the muscle by an augmentation of its nutrition. Hence it is that the more a muscle is exercised, the more vigorous and more bulky does it become, provided it receives an adequate supply of nutritive material. This is equally the case, whether the exercise of the muscle be voluntary or not. We see examples of it in the arms of the smith and in the legs of the opera-dancer; and we have a still more striking manifestation of it in those cases, in which an obstruction to the exit of urine through the urethra has called for increased efforts on the part of the bladder, the continuance of which gives rise to an extraordinary augmentation in the thickness of its muscular coat.

361. We have already seen that the presence of certain products

of disintegration in Muscles which have been subjected to repeated stimulation, affords evidence that their activity involves a *waste* of their substance; and the amount of this disintegration seems to bear a proportion to the quantity of force which the muscles are called on to put forth. For the restoration of the power of the muscles, a regeneration of their substance, at the expense of nutritive material supplied by the blood, is consequently requisite. There are certain muscles, as the Heart and the muscles of Respiration, whose action is necessarily constant; and their reparation must take-place as unceasingly as their waste. In these muscles, no sense of fatigue is ever experienced. But in the muscles which are usually put in action by the will, this is not the case. Any prolonged exertion of them induces fatigue; and this fatigue is an evidence of their impaired condition, and of the necessity of rest to impart to them a renewal of vigour. The *rest* of such muscles is essential to the recovery of their powers; and this recovery is partly due to the nutritive operations, which then take-place unchecked so as to repair the losses previously sustained, and partly (it would seem) to the conveyance-away of those products of disintegration, the retention of which in the muscular substance impairs its contractility.

362. Thus we see that the property of Contractility is a vital endowment peculiar to Muscular tissue, and is dependent for its existence upon the due nutrition of that tissue; that it may be called into exercise by certain stimuli, applied either to the muscle itself, or to the nerve supplying it, provided that the muscle be also permeated with oxygen; that it may be exhausted by repeated stimulation, but is then recovered by rest, provided that fresh nutritive material is brought by the circulating current, and that effete matter is conveyed away; that the nutrition of the muscle is impaired by continued repose, and that its contractility diminishes in the same proportion; that the nutrition is increased by frequent use, and that the power of the muscle then augments in like degree; and finally that the departure of muscular power, which ensues upon the general death of the system, is dependent in part upon the cessation of the supply of oxygen, and in part upon changes in the composition of the muscle itself, which are no longer compensated by the functions that keep it in its normal condition during life.—The rapidity of these changes is the greatest in warm-blooded animals, in which also the muscular contractility is most dependent upon the presence of oxygen in the muscular substance; hence the contractility departs after death much more speedily in these, than in cold-blooded animals.

363. It has been ascertained by the researches of MM. Becquerel and Breschet, confirmed by those of Prof. Helmholtz, that the temperature of a Muscle rises when it is thrown into energetic contraction. The increase is ordinarily but about 1° Fahr.; but

it may amount to twice as much if the same muscle be kept in action for some time, as in the exercise of sawing. This effect might be attributed to the chemical changes taking place in the muscle, the components of which undergo a more rapid oxidation when it is thrown into activity; but it is probable that the force thus generated is expended in producing Motion, and that the increase of Heat is due rather to the augmented flow of blood through the muscle,—perhaps also to the friction which its exercise occasions between its component particles.

364. The experiments of M. du Bois-Reymond have shown that the different parts of any living Muscle are in different Electric states in regard to each other. The most powerful influence on the Galvanometer is produced when a portion of the natural *surface* of the muscle is placed on one of the electrodes, and a portion of the surface exposed by transverse *section* is laid on the other; the former being positive to the latter. And a less considerable though decided difference is seen when different parts of the surface or of the transverse section are compared; the general fact being that the points lying nearer the surface of the muscle are positive to those nearer to its interior. Thus a current of Electricity exists in every muscle in which the ordinary nutritive changes are going on; and its energy bears a close relation to the activity of those changes. There is reason to believe that every integral part of the muscular substance is a centre of electro-motor action; and that the current shown by the entire muscle when it is made to form part of a circuit is a *derived* current, produced by incomparably more intense currents circulating in the interior of the muscle around these ultimate particles.

365. That a change in the Electric state of Muscles takes place in the act of contraction, was first ascertained by the experiments of Prof. Matteucci; but he was led by them to believe that the 'muscular current' is augmented in force. The contrary, however, has been ascertained beyond all doubt, by the researches of Bois-Reymond; who has shown that the electro-motive power exhibited by a Muscle is diminished or even reduced to zero when it is made to contract,—as if the changes which operate to produce disturbance of Electric equilibrium when the muscle is at rest, are concerned in the development of Mechanical force when it is thrown into contraction. This phenomenon may be exhibited by making the two arms form part of a circuit connected with a Galvanometer of sufficient sensitiveness, and throwing the muscles of one of them into a state of powerful contraction. Various precautions are requisite, however, in order to secure accuracy in the results of this experiment.

366. We have now to consider that property of Muscles, which has been distinguished as *Tonicity;* its tendency being to maintain a persistent or *tonic* contraction in Muscular fibre. The

ground for considering this property as a form of *vital* Contractility, rather than as a modification of *physical* Elasticity, is mainly this,—that it persists only for a limited time after the general death of the body, and departs before the commencement of obvious decomposition. But there now seems adequate reason for the belief that this property is in reality nothing else than Elasticity; and that its apparent peculiarity arises out of the special conditions under which the muscle is placed in the living body, as compared with the dead. It has been shown by Weber that living Muscles possess a very *perfect* though *weak* elasticity; that is, they readily yield to an extensile force, and return again on its withdrawal exactly to their previous length. Hence in the ordinary motions of a limb, the elasticity of one set of muscles opposes no considerable obstacle to the contraction of its antagonists; whilst it is sufficient to cause the former to recover their previous condition when left free to do so by the relaxation of the latter. But Weber also ascertained the curious fact that the elasticity of muscle is even less in their contracted than in their passive condition, that is, the same extensile force produces a greater lengthening; and this diminution of elasticity becomes more and more decided in proportion to the continuance of the contractile action, the extensibility of the muscle increasing as its contractility becomes exhausted. In *dead* muscles, on the other hand, the Elasticity is *greater* than during life, that is, it presents a greater resistance to an extensile force; but it is *less perfect*, the dead muscle not entirely resuming its previous condition after being stretched, and tearing more readily than one which still retains its vitality.—These differences are pretty certainly to be referred on the one hand to diversities in the molecular attractions of the particles of Muscle, occasioned by the nutritive and other changes to which it is subject during life; and on the other to alterations affecting the physical condition of the muscle, which are very likely to commence immediately on the cessation of those changes, though not yet manifesting themselves in evident decomposition.

367. The Elasticity of Muscular tissue manifests itself in the retraction which takes-place in the ends of a living muscle when it is divided; the retraction being permanent, and greater than that of a dead muscle. In the healthy state it would seem as if the elasticity of the several groups of muscles is so adjusted as to be in mutual counterpoise; but the balance is destroyed, when, in consequence of paralysis, or of impaired nutrition from other causes, the elasticity of one set is weakened. This is the case, for example, in lead palsy; in which the extensors of the fore-arm and hand lose their power, so that the tonic contraction of the flexors keeps the fingers constantly bent upon the palm. It would seem, however, that the elasticity of the flexors is usually greater than that of the extensors; as the former predominate when all

are equally withdrawn from the control of the nervous system in profound sleep.

368. The *Rigor Mortis*, or death-stiffening of the Muscles, supervenes after the Contractility of the muscles has departed, but before any putrefactive change has commenced. This phenomenon is rarely absent; although it may be so slight, and may last for so short a time, as to escape observation. The period which elapses before its commencement is as variable as its duration; and both seem to be dependent upon the vital condition of the system at the time of death. When it has been weakened or depressed by previous disease, the contractility of the muscles speedily departs; and the stiffening comes-on early, and lasts but a short time. Thus, after death from Typhus, the limbs have been sometimes known to stiffen within 15 or 20 minutes. On the other hand, when the general vigour of the system has not been previously impaired, and death has resulted from some sudden cause, the contractility of the muscles is more persistent, and their stiffening is deferred and lasts longer. The commencement of this rigidity in the Human body usually takes-place within seven hours after death; but twenty or even thirty hours may elapse before it shows itself. Its general duration is from twenty-four to thirty-six hours; but it may pass-off much more rapidly, or it may be prolonged through several days. It affects all the muscles composed of the striated fibre with nearly the same intensity; except that the flexors usually contract more strongly than the extensors (as in sleep), the fingers being closed upon the palm, the hand bending on the fore-arm, and the lower jaw being drawn firmly against the upper. And it even manifests itself in muscles that have been thrown out of use by paralysis, provided that their nutrition has not been seriously impaired.

369. The Rigor Mortis is manifested also in the Non-striated fibre of which the Muscular coat of the Alimentary canal is composed; and most remarkably in the muscular structure of the Heart and Blood-vessels. As soon as the muscular walls of the several cavities lose their irritability, they begin to contract forcibly upon their contents, and thus become stiff and firm, although they were previously flaccid. The ventricles of the Heart, which are the first parts to lose their contractility, become rigid and contracted within an hour or two after death; and usually remain in that state for ten or twelve hours, sometimes for twenty-four or thirty-six, then again becoming relaxed and flaccid. This rigid contracted state of the heart, in which the walls are thickened and the cavities diminished, was formerly supposed to be a result of disease, and was termed 'concentric hypertrophy'; but it is now known to be the natural condition of the organ at the period when the rigor mortis occurs in it. The contraction of the Arterial tubes is so great as to produce for the time a great diminution in their calibre; and this doubtless contributes to the passage of the

blood from the arterial into the venous system, which almost invariably takes-place within a few hours after death. The arteries then enlarge again and become quite flaccid, their tubes being emptied of their previous contents; and it was from this circumstance, that the ancient physiologists were led to imagine that the arteries are not destined to carry blood, but air.—As soon as the Rigor Mortis departs, the muscles pass into a state of decomposition.

370. There are many remarkable points of correspondence between the Rigor Mortis and the Coagulation of the Blood, which have induced some physiologists to believe that the death-stiffening is in fact nothing else than the coagulation of the blood in the muscles. Although there is not at present any adequate ground for this conclusion, yet a relation between the two phenomena would seem to be indicated by the similarity of the effects which sudden and violent shocks to the nervous system, or the exhaustion produced by violent and long-continued exertion (as when animals are run to death) produce upon both; the coagulation of the blood and the stiffening of the muscles either not taking place at all, or being very imperfect, and speedily giving place to putrefactive changes. On the other hand, it has been ascertained that the muscles of the living body will exhibit the same rigidity, if the circulation of the blood through them be interrupted for a time, or the current of blood be replaced by one of warm water; the contractility thus suspended returning, and the rigidity passing off, on the re-establishment of the blood-circulation.

371. The *Nervous System*, taken as a whole, is the instrument of all those operations which peculiarly distinguish the Animal from the Plant; and it serves many additional purposes connected with the Organic or Vegetative functions, which the peculiar arrangements of the Animal body involve. Wherever a distinct Nervous System can be made-out (which has not yet been found possible in the lowest Animals), it consists of two very different forms of structure, the presence of both of which, therefore, is essential to our idea of it as a whole. We observe, in the first place, that it is formed of *trunks* which are distributed to the different parts of the body, especially to the Muscles and to the Sensory surfaces; and of *ganglia* which sometimes appear merely as knots or enlargements on these trunks, but which in other cases have rather the character of central masses from which the trunks proceed. The trunks are essentially composed of *nerve-fibres;* whilst the ganglionic centres are characterized by the presence of *vesicular substance* consisting of peculiar cells connected with these fibres. Now it is easily established by experiment that the *active powers* of the nervous system reside in the *ganglia*, and that the *trunks* serve merely as *conductors* of the influence which is to be propagated towards or from them. For

if a trunk be divided in any part of its course, all the parts to which the portion thus cut-off from the ganglion is distributed, are completely paralysed; that is, no impression made upon them is felt as a sensation, and no motion can be excited in them by any act of the mind. Or if the substance of the ganglion be destroyed, all the parts which are exclusively supplied by nervous trunks proceeding from it, are in like manner paralysed. But if, when a trunk is divided, the portion still connected with the ganglion be pinched, or otherwise irritated, sensations are felt, which are referred to the points supplied by the separated portion of the trunk; which shows that the part remaining in connection with the ganglion is still capable of conveying impressions, and that the ganglion itself receives these impressions and makes them felt as sensations. On the other hand, if the separated portion of the trunk be irritated, motions are excited in the muscles which it supplies; showing that it is still capable of conveying the motor influence, though cut-off from the usual source of that influence.

372. When we minutely examine the trunk of a nerve, we find that it is composed, in the first place, of a *Neurilemma* or nerve-sheath, consisting of Connective tissue; the office of which is evidently that of protecting the nerve-tubes and of isolating them from the surrounding structures, at the same time that it allows blood-vessels to pass into the interior of the trunk. From the interior of the neurilemma, thin layers of Connective tissue pass into the midst of the enclosed bundle of nervous fibres; separating it into numerous smaller fasciculi, which are thus bound together and supplied with blood-vessels. The capillaries are distributed very much on the same plan as those of Muscular tissue (Fig. 104); the network being composed of straight vessels which run along the course of the nerve between the nerve-tubes, and are connected at intervals by transverse vessels. When the neurilemma has been removed, and the trunk has been separated into its component fasciculi, we may still further subdivide the fasciculi themselves by careful dissection, until we arrive at the ultimate Nerve-fibre, which is the essential element of the structure. Two forms of this fibre exist in the nerves of higher animals; one being known as the *tubular*, whilst the other, which seems to be in a state of less complete development, is distinguished as the *gelatinous*. These require a separate description.

373. The Nerve-fibre, in its most complete form, is distinctly *tubular*. It is composed externally of a very delicate transparent membrane, which is apparently quite homogeneous; it is not penetrated by blood-vessels, nor does it branch or anastomose with others, and there is reason to believe it to be continuous from the origin to the termination of the nervous trunk. Within the tube is a hollow cylinder, of a material known as the *medul-*

lary sheath or *white substance of Schwann*, which differs in composition and refracting power from the matter that occupies the centre of the tube; in the perfectly fresh nerve-tube it is viscid and transparent like a thick oil; but under the influence of cold, of water, and of various re-agents, it undergoes a sort of coagulation, which gives to the fibre a 'double contour' (Fig. 106, *b*). The centre or axis of the tube is occupied by a transparent substance which is termed the *axis-cylinder:* this is especially distinguished from the preceding by its greater firmness and

Fig. 106.*

elasticity, resembling coagulated albumen both in its consistence and in its chemical characters. There is reason to believe that the 'axis-cylinder' is the essential component of the nervous fibre; and that the nerve-medulla which surrounds it, serves, like the membranous investment, chiefly for its complete isolation. The whole of the matter contained in the tubular sheath is extremely soft; yielding to a very slight pressure. The tubular sheath itself varies in density in different parts, being stronger in

* Stellate ganglionic cell, from Human Brain; one of its prolongations, *a*, becoming continuous with the axis-cylinder of a double-contoured nerve-fibre, *b*.

the nerve-trunks than in the substance of the brain and spinal cord. In the former the regular form of the nerve-tube is a perfect cylinder; though a little disturbance will cause an alteration in this,—a small excess of pressure in one part forcing the medullary substance towards another where it is more free to accumulate, and thus producing a swelling. The greater delicacy of the tubular sheath in the latter causes this result to take-place with yet more readiness; so that a very little manipulation exercised upon the fibres of the brain and spinal cord, or on those of special sense, occasions them to assume a *varicose* or beaded appearance (Fig. 107, A). When the fibres of these parts, however, are examined without any such preparation, they are found to be as cylindrical as the others.—The diameter of the tubuli is usually between 1-2000th and 1-4000th of an inch. Sometimes, however, it is as much as 1-1500th; and occasionally as little as 1-14,000th. They are larger in the nerve-trunks than in the brain; and they diminish in the latter as they approach the cortical substance. The fibres of the nerves of special sense are smaller than the average, in every part of their course.

Fig. 107.*

374. The *gelatinous* fibres cannot be shown to consist of the same variety of parts as the preceding; the tubular envelope is often undistinguishable, and the nerve-medulla is altogether wanting. They are flattened, soft, and homogeneous in their appearance, and are often seen to contain nuclei which are arranged with tolerable regularity. These nuclei are brought into view by acetic acid, which dissolves the rest of the fibre, leaving them unchanged. The gelatinous fibres are usually of smaller size than the tubular, their diameter averaging between the 1-6000th and the 1-4000th of an inch; and they sometimes show a disposition to split into very delicate fibrillæ. Being of a yellowish-grey colour, they have been sometimes distinguished as the *grey* fibres. — These two classes of fibres have been supposed to be essentially distinct in character and office; the 'tubular' having been regarded as ministering to the *Animal* functions of sensation and motion; and the 'gelatinous' as connected with the *Organic* or nutritive operations. The facts which will be presently stated (§ 388)

* Gelatinous nerve-fibres from Olfactory Nerve.

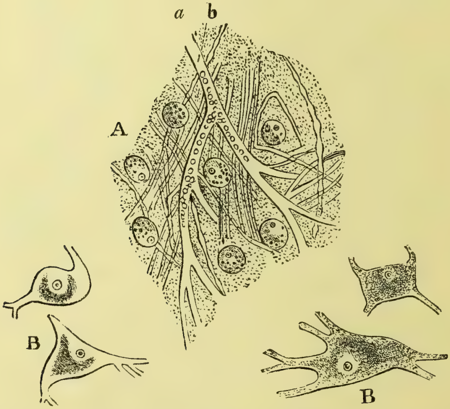
regarding their origin, however, as well as their joint existence in almost every nerve, are decidedly adverse to this view; and we shall find reason to consider them as differing chiefly in grade of development. Indeed it appears that the very same fibre may be 'tubular' in one part of its course and 'gelatinous' in another.

375. The Nerve-fibres ordinarily appear to run continuously from one extremity of a nervous cord to the other, without any union or anastomosis; each ultimate fibre probably having its distinct office, which it cannot share with another. The fasciculi, or bundles of fibres, however, occasionally intermix and exchange fibres with each other; and this interchange may take-place among either the fasciculi of the same trunk, or among those of different trunks. Its object is evidently to diffuse among the different branches the endowments of a particular set of fibres. Thus we shall hereafter see that, in all the Spinal Nerves of Vertebrata, one set of roots ministers to sensation, and another to motion; the sensory fibres are *principally* distributed to the Skin, and the motor fibres to the Muscles; but every branch contains both sensory and motor fibres, which are brought together by the interlacement of those connected with both sets of roots. In the head, we have some nervous trunks which have sensory roots alone, and others which have motor roots only; these in like manner acquire each other's functions in some degree by an interchange of filaments,—the sensory trunk receiving motor fibres, and the motor trunk receiving sensory fibres. An interchange of this kind upon a very extensive scale takes-place between the Cerebro-spinal system, whose ganglionic centres are the brain and spinal cord, and the Sympathetic system, whose centres consist of a number of scattered ganglia. The former sends a large number of fibres into the latter by the twigs of communication near the origins of the Spinal nerves, as well as by their connecting branches; whilst the latter sends a smaller number of fibres into the former, these being chiefly of the gelatinous kind.

376. Sometimes we find the fasciculi of several distinct trunks united into an extensive *plexus;* one object of which appears to be, to give a more advantageous distribution to fibres which all possess corresponding endowments. Thus the *brachial* plexus mixes together the fibres arising by five pairs of roots, on either side, from the spinal cord; and sends off five principal trunks to supply the arm. Now if each of these trunks had arisen by itself from a distinct segment of the spinal cord, so that the parts on which it is distributed had only a single connexion with the nervous centres, they would have been much more liable to paralysis than they are. By means of the plexus, every part is supplied with fibres arising from each of the five segments of the spinal cord; and the functions of the whole must therefore be suspended, before complete paralysis of any part could occur

from a cause which operates above the plexus. This may be experimentally shown on the Frog, whose crural plexus is formed by the interlacement of the component fasciculi of three trunks on each side; for section of the roots of one of these produces little effect on the general movements of the limb; and even when two are divided, there is no paralysis of any of its actions, all being weakened in nearly an equal degree.—It is probable, however, that another use of this arrangement is to bring *groups of muscles* into relation with the different segments of the Cord, in such a mode that their actions may be combined and harmonized. We shall hereafter (CHAP. XIII.) find reason to believe that the Will does not at once act through the nerves upon the muscles, but that it plays (so to speak) upon the Spinal cord, each segment of which has its own particular endowments, and ministers to a particular set of movements. And thus the greater the variety of movements which any part is destined to perform, the more complicated will be the nervous plexus by which its muscles are connected with the centres of motion.

Fig. 108.*

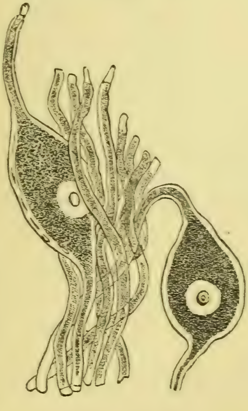


377. The second primary element of the Nervous System, distinguished as the vesicular substance, is composed of nucleated

* Primitive fibres and ganglionic cells of Human Brain, after Purkinje :—A, ganglionic cells lying amongst varicose nerve-tubes and blood-vessels, in substance of optic thalamus; *a*, small vascular trunk:—B, B, cells with variously-formed peduncles, from dark portion of crus cerebri.

cells, containing a finely granular substance, and lying somewhat loosely in the midst of a minute plexus of blood-vessels (Fig. 108, A). Their normal form may be regarded as globular (hence they have been termed *nerve-* or *ganglion-globules*); but this is liable to alteration from the compression they suffer, so that they become oval or polygonal. The most remarkable change of form, however, which they undergo, is by an extension into one or more long processes, giving them a *caudate* or a *stellate* aspect (B, B), These processes are composed of a finely-granular substance, resembling that of the interior of the vesicle, with which they seem to be distinctly continuous; and if traced to a distance, they are found to become continuous either with the axis-cylinders of the nerve-tubes (Fig. 106), or with similar prolongations from other cells. It has been common to distinguish the nerve-cells as 'unipolar,' 'bipolar,' or 'multipolar,' according as they are connected with one, two, or several nerve-fibres; and it has been held, also, that some nerve-cells are destitute of direct connection with nerve-fibres. The recent enquiries of Prof. Beale, however, have rendered it probable that all nerve-cells are really 'bipolar,' that is, connected with two fibres, as shown in Fig. 109; and that where several processes are given off, which is especially the case in certain parts of the central organs in Man, these are for the mutual connection of the nerve-cells. A distinct membranous cell-wall cannot be always demonstrated; indeed it would seem in some instances to be pretty certainly wanting. The substance of the cell is essentially composed of an albuminoid material, with which are mingled a great quantity of granules; these are for the most part fine and pale, but they are sometimes large and dark, and then either give a reddish or yellowish-brown colour to the whole cell, or accumulate in masses near the nucleus, which is usually conspicuous (Fig. 108).—The size of the ganglionic cells is liable

Fig. 109.*

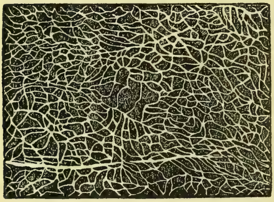


* Bipolar Ganglionic Cells and nerve-fibres, from ganglion of the Fifth Pair in Lamprey.

to great variation; the globular ones are usually between 1-300th and 1-1250th of an inch in diameter.

378. The vesicles just described are aggregated together in masses of variable size; and are in some degree held together by the plexus of Blood-vessels (Fig. 110) in the midst of which they lie. They are sometimes imbedded in a soft granular substance, which adheres closely to their exterior and to their processes; this is the case in the outer part of the cortical substance of the Human Brain. In other instances, each cell is enclosed in a distinct envelope, composed of smaller cells closely adherent to one another and to the contained cell; such an arrangement is common in the smaller ganglia, and in the inner portion of the cortical substance of the brain.—The substance which is made-up of these peculiar cells, of the plexus of the blood-vessels in which they lie, and of the granular matter that is disposed amongst them, is altogether known as the *cineritious* or *grey* substance; being distinguished by its colour, in Man and the higher animals at least, from the *white* substance (composed of nerve-tubes) of which the trunks of the nerves, as well as a large part of the Brain and Spinal cord, are made-up. But this distinction is by no means constant; for the grey colour, which is partly due to the pigment-granules of the cells, and partly to the redness of the blood in the vessels, is wanting in the Invertebrata generally, and is not characteristically seen in the classes of Fishes and Reptiles. Moreover, when the ganglionic substance exists in small amount, even in Man, its colour is not sufficiently intense to serve to distinguish it; and, as we have already seen, there are nerve-fibres which possess a greyish hue. The real distinction evidently lies in the *form* of the ultimate structure, which consists of *nerve-fibres* in the one case, and of *ganglionic cells* in the other; and these terms will be henceforth used to characterize the two kinds of Nervous tissue which have been now described.

Fig. 110.*

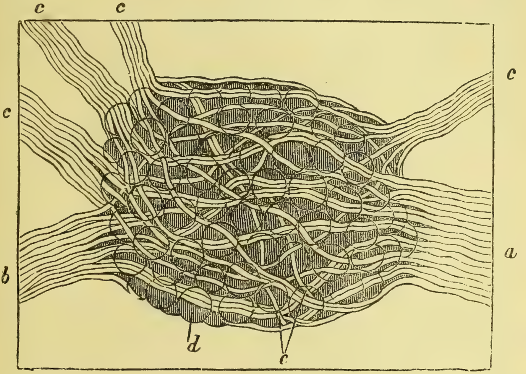


379. A *ganglion*, then, essentially consists of a collection of nerve-vesicles or ganglionic-cells, interspersed among the nerve-fibres; and it is in the presence of the former that it differs from a *plexus*, which it frequently resembles in the arrangement of the latter. When a nerve enters a ganglion, its component fibres separate and pass into the ganglion in different directions, so as

* Capillary network of Nervous Centres.

to be variously distributed among the branches which pass out of it (Fig. 111); some of them coming, in its interior, into connection with its peculiar cells, whilst others merely pass between

Fig. 111.*



these. All the nervous centres of Invertebrated animals are constructed upon this general plan; but among Vertebrated animals it is for the most part only in the Sympathetic system that the vesicular matter is distributed through a number of small and isolated ganglia, whence this is sometimes distinguished as the 'ganglionic' system. The Brain of Vertebrata is really composed of an aggregation of several ganglionic masses, as very plainly appears from the study both of its development and of its comparative structure; and the Spinal Cord in like manner is one long continuous ganglionic tract, formed by the coalescence of the ganglionic centres of the successive segments of the body.—The only exception to the general fact that the vesicular matter occupies the centre of the ganglia, occurs in the Cerebral Hemispheres and Cerebellum of Vertebrata, in which it is chiefly disposed on the exterior, forming the *cortical* envelope. The reason for this variation is probably to be found in the very large amount of this substance which the brain of the Vertebrata contains; and in the necessity of the free access of blood-vessels to it, which is

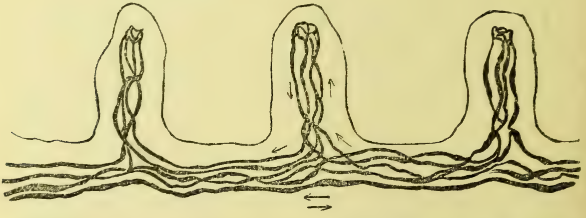
* Dorsal Ganglion of Sympathetic nerve of Mouse:—*a*, *b*, cords of connection with adjacent sympathetic ganglia; *c*, *c*, *c*, *c*, branches to the viscera and spinal nerve; *d*, ganglionic cells; *e*, nervous fibres crossing the ganglion.

provided-for by a great extension of its surface beneath the investing vascular membrane (Pia Mater), more readily than it could be in any other mode.

380. But the vesicular matter is not found in the *central* masses only of the nervous system; for it presents itself also at certain parts of the *surface* or *periphery*, which are peculiarly destined to receive the impressions that are to be conveyed to the central organs. Thus the expansion of nerve-substance which forms the Retina, essentially consists of a layer of ganglionic corpuscles or nerve-cells, with a minute plexus of vessels, possessing all the essential characters of the vesicular substance of the brain; and something of the same kind has been seen in connection with the corresponding expansions of the Olfactive and Auditory nerves. Moreover, the study of the history of the development of the Eye has shown that the vesicular matter of the Retina is an offshoot (so to speak) from that of the Optic ganglion; the fibres of the connecting nerve being interposed between the cells of the peripheral and those of the central organs, for the sake of transmitting to the latter the changes which had originated in the former.

381. The ultimate distribution of the nerve-fibres in the Skin and Tongue has not been so clearly made-out. There is reason, however, to believe that the axis-cylinder of the nerve-fibres is continued beyond the termination of the medullary sheath, and that it subdivides into a bundle of *fibrillæ* which form plexuses of great minuteness by inosculation with those proceeding from other fibres. A like subdivision and formation of plexuses probably takes-place at the extremities of the tactile and gustative papillæ (Fig. 112). These plexuses, indeed, are

Fig. 112.*



probably to be regarded in the light of peripheral ganglionic expansions; for it has been shown by the observations of Prof.

* Diagram of the distribution of the nerve-fibres in the papillæ of the tongue of the Frog.

Kölliker upon the tail of the Tadpole, that the nervous plexuses are formed in the same manner as the capillary net-work; namely, by the inosculation of the prolongations of radiating cells, whose centres are at a considerable distance from each other.

382. The fibres of the Nerve-trunks appear to originate, according to the observations of Prof. Kölliker, in cells which become fusiform by elongation, and which then coalesce at their extremities; and these seem to increase, after the first formation of the trunks, by the longitudinal subdivision of fusiform cells which had not previously undergone complete metamorphosis into fibres, as well as by the development of cells *de novo*. The nuclei of the original cells may be frequently seen in the nerve-tubes at a later period, lying between their membranous walls and the substance deposited in their interior. The earliest condition of both forms of nerve-fibre appears to be precisely the same; but the *gelatinous* remains in a state nearly resembling this, whilst the *tubular* is developed into a higher form. This development seems essentially to consist, as in the case of other tissues, in the production of peculiar 'formed materials'—the external membrane and the medullary sheath—from the exterior of the previously homogeneous cord which remains as the axis-cylinder; and it is a fact of importance, as indicative of the close relationship of the latter to the primitive 'germinal matter,' that it readily dyes with carmine, which scarcely tinges its enveloping structures.

383. We have now to notice the Chemical Composition of Nervous matters; of which, however, it is not yet possible to give a satisfactory account. The proportion of Water it contains is large, varying from 70 to 85 per cent.; in the Brain it seems to average about 75 per cent. Of the 25 parts of solid matter, about 15 parts consist of Fatty substances, 7·5 of Albuminous Compounds, 1·5 of Salts, and 1 of Extractive Matters. The Fatty substances seem to be partly contained in the cells, but to form the special components of the 'medullary sheath' of the tubular fibres. The Albuminous compounds, on the other hand, probably constitute the membranous walls of the cells and a portion of their contents; whilst in the tubular fibres they would seem to be the material of the 'axis-cylinder' as well as of the membranous envelope. It is chiefly with the Fatty matter, which constitutes about a third of the solid substance, that the attention of Chemists has been occupied. This is stated by M. Fremy (one of the most recent analysts) to contain, besides the ordinary fatty matters, and Cholesterine or biliary fat, two peculiar fatty acids, termed the Cerebric and the Oleo-phosphoric. *Cerebric* acid, when purified, is white, and presents itself in crystalline grains. It contains a small proportion of Phosphorus; and differs from the ordinary fatty matters in containing Nitrogen,

ss also in containing twice their proportion of oxygen. *Oleo-phosphoric* acid is separated from the former by its solubility in ether; it is of a viscid consistence; but when boiled for a long time in water or alcohol, it gradually loses its viscidity, and resolves itself into a pure oil, which is elaine, while phosphoric acid remains in the liquor. The proportion of phosphorus in the brain is considerable; being from 8 to 18 parts in 1000 of the whole mass, or from 1-20th to 1-30th of the whole solid matter. It seems to be unusually deficient in the brain of idiots.

384. Various circumstances lead to the belief that the Nervous tissue, during the whole period of active life, is continually undergoing changes in its substance by decay and renewal. We know that, after death, it is one of the first of all the animal tissues to exhibit signs of decomposition; and there is no reason to suppose that this tendency is absent during life. The researches of Dr. Waller upon the results of section of Nerve-trunks, have shown that their constituent fibres undergo rapid degeneration when cut off from connection with their ganglionic centres, notwithstanding that they are fully supplied with blood. Hence, for the simple maintenance of its normal character, a considerable amount of nutritive change must be required. But many circumstances further lead to the conclusion, that Nervous matter is subject to a *waste* or *disintegration* which bears a proportion to the activity of its operations;—or, in other words, that every act of the Nervous system involves the death and decay of a certain amount of Nervous matter, the replacement of which will be requisite in order to maintain the system in a state fit for action. We shall hereafter see that there are certain parts of the Nervous system, particularly such as put in action the respiratory muscles, which are in a state of unceasing, though moderate, activity; and in these, the constant nutrition is sufficient to repair the effects of the constant decay. But those parts which operate in a more powerful and energetic manner, and which therefore waste more rapidly when in action, need a season of rest for their reparation. Thus a sense of fatigue is experienced, when the mind has been long acting through its instrument—the brain; indicating the necessity for rest and reparation. And when *sleep*, or cessation of the cerebral functions, comes on, the process of nutrition takes place with unchecked energy, counterbalances the results of the previous waste, and prepares the organ for a renewal of its activity. In the healthy state of the body, when the exertion of the Nervous System by day does not exceed that which the repose of the night may compensate, it is maintained in a condition which fits it for constant moderate exercise; but unusual demands upon its powers,—whether by the long-continued and severe exercise of the intellect, by excitement of the emotions, or by the combination of both in that state of *anxiety* which the circumstances of

Man's condition too frequently induce,—occasion an unusual waste; and hence for the complete restoration of its powers a prolonged repose is required.

385. There can be no doubt that (from causes which are not known) the amount of Sleep required by different persons, for the maintenance of a healthy condition of the Nervous System, varies considerably; some being able to dispense with it to a degree which would be exceedingly injurious to others of no greater mental activity. Where a prolonged exertion of the mind has been made, and the natural tendency to sleep has been habitually resisted by a strong effort of the will, injurious results are sure to follow. The bodily health breaks-down, and too frequently the mind itself is permanently enfeebled. It is obvious that the nutrition of the Nervous system becomes completely deranged; and that the tissue is no longer formed in the manner requisite for the discharge of its healthy functions.

386. An unusual Disintegration of the *nervous* matter seems to be indicated by an increase in the amount of *phosphatic* deposit in the Urine. No others of the soft tissues contain any large proportion of phosphorus; and the marked increase in these deposits, which has been continually observed to accompany long-continued *wear* of mind, whether by intellectual exertion, or by anxiety, can scarcely be set-down to any other cause. The most satisfactory proof is to be found in cases in which there is a periodical demand upon the mental powers—as, for example, among clergymen, in the preparation for, and discharge of, their Sunday duties;—this being almost invariably followed by the appearance of a large quantity of the phosphates in the urine. And in cases in which constant and severe intellectual exertion has impaired the nutrition of the brain, and has consequently weakened the mental power, it is found that any premature attempt to renew the activity of its exercise causes the re-appearance of the excessive phosphatic discharge, which indicates an undue waste of nervous matter.

387. As the disintegration of the Nervous System is thus proportional to its exercise, so must its reparation make a corresponding demand upon the nutritive processes. And accordingly we find that it is very copiously supplied with blood-vessels; and that the amount of food appropriated to its maintenance in an active condition is very considerable. This we know from the fact, that persons of active minds but sedentary bodily habits commonly require nearly as much food as those in whom the waste of the Muscular system is greater and that of the Nervous system less, in virtue of their bodily activity and the less energetic operation of their minds.

388. The *regeneration* of Nervous tissue is easily proved in regard to the Fibrous substance, by the return of the sensory and

motor endowments of parts whose nerves have been divided; and various considerations lead to the belief that this is effected, not by a simple reunion of the cut ends that are in apposition, but by an entirely new development of nerve-fibres in the part of the trunk that has been separated from its central connections. All our knowledge of the functions of the nervous system leads to the belief, that *perfect continuity* of the nerve-tubes is requisite for the conduction of an impression of any kind, whether this be destined to produce motion or sensation; and various facts, well known to Surgeons, prove that such continuity may be re-established by a new production of nervous substance. In the various operations which are practised for the restoration of lost parts, a portion removed from one spot is grafted, as it were, upon another; its original attachments are more or less completely severed,—frequently altogether destroyed,—and new ones are formed. Now in such a part, so long as any of its original nervous connections exist, and new ones are not yet completely formed, the sensation is referred to the spot from which it was taken; thus when a new nose is made by partly detaching and bringing-down a piece of skin from the forehead, the patient at first feels, when anything touches the tip of his nose, as if the contact were really with his forehead. After time has been given, however, for the establishment of new connections with the parts into whose neighbourhood it has been brought, the old connections of the grafted portion are completely severed, and an interval then ensues during which it frequently loses all sensibility; but after a time its power of feeling is restored, and the sensations received through it are referred to the right spot.—A more familiar case is the regeneration of Skin containing sensory nerves, which takes-place in the well-managed healing of wounds involving loss of substance. Here there must obviously be, not merely a prolongation of the nerve-tubes from the subjacent and surrounding trunks, but also a formation of new sensory papillæ.—A still more striking example of the regeneration of Nervous tissue, however, is to be found in those cases (of which there are now several on record), in which portions of the extremities that have been completely severed by accident, have been made to adhere to the stump; and have, in time, completely recovered their connection with the Nervous as with the other systems, as is indicated by the restoration of their sensory and motor endowments.—Of the degree in which the Vesicular substance of the Nervous system may be regenerated, we have no certain knowledge; but there can be little doubt, considering the activity of its usual nutritive changes, that a complete reproduction may be effected in cases of loss of substance, where it can commence from a neighbouring mass of the same tissue.

389. We have now to inquire into the conditions under which

the peculiar properties of the Nervous System are manifested in an active form; and it will first be desirable to explain, somewhat more in detail, the nature of the different operations to which it is subservient. These operations present themselves under their most complex form in Man and the higher animals; but they may often be most satisfactorily studied in the lower. Certain fundamental facts, however, may be best learned from our own experience. Thus, in the first place, when an *impression* is made upon any part of the surface of the body by mechanical contact, by heat, electricity, or any other similar agent,—or upon the organs of special sense (the eye and ear, the nose and tongue), by light or sound, by odorous or sapid bodies,—these impressions, in the healthy and wakeful state of the Nervous System, are *felt as sensations;* that is, the mind is rendered conscious of them. Now there can be no doubt that the Mind is immediately influenced, not by the impression on the remote organ, but by a certain change in the condition of the Brain, excited or aroused by that which has originated elsewhere. For if the communication with the brain be cut-off, no impression on the distant parts of the nervous system is felt, notwithstanding that the mind remains perfectly capable of receiving it. The mind, then, is only rendered conscious of external objects, by the influence they indirectly exert upon the *brain*, or upon a certain part of it, which, being the peculiar seat of sensation, is called the *Sensorium*. Hence we recognize, in the process by which the Mind is rendered conscious of external objects, three distinct stages;—first, the reception of the impression at the extremities of the sensory nerve; second, the conduction of the impression, along the trunk of the nerve, to the sensorium; third, the change excited by it in the sensorium itself, through which the sensation is produced. Here, then, the change in the condition of the Nervous system commences at the circumference, and is transmitted to the centre; and the fibres which are concerned in this transmission are termed *sensory*.

390. On the other hand, when an Emotion, an Instinctive impulse, or an act of the Will, operates through the Brain to produce a muscular contraction, the first change is in the condition of the vesicular substance of that organ. The influence of this change is transmitted by the motor nerves to the muscles among which they are distributed; and the desired movement is the result. Here, too, we have at least three stages;—first, the origination of the change by an impression acting on the central organ; second, the conduction of that change along the motor nerves; and third, the stimulation of the muscles to contraction. But the operation here commences at the centre; and the effects of the change in the brain are transmitted to the circumference, by a set of nervous fibres which are termed *motor*. The complete distinctness of these two classes of fibres was first established by Sir C. Bell. It is

best seen in the cranial nerves, of which some are purely sensory, and others purely motor; but it may also be clearly proved to exist at the *roots* of the Spinal nerves (although their *trunks* possess mixed endowments), the posterior being sensory, whilst the anterior are motor.

391. But although sensations can only be felt through the Brain, and voluntary motions can only be produced by an action of the mind through the same organ, yet there are many changes in the animal body wherein the nervous system is concerned, which yet do not involve the operation of the brain; being produced without our Consciousness being necessarily excited, and without any act of the Will, or even in opposition to its efforts. Of these actions, the Spinal Cord of Vertebrata and its prolongation within the cranium are the chief instruments; in the Invertebrate animals they are performed by various ganglia, which are usually disposed in the neighbourhood of the organs to which they minister. If the Spinal Cord of a Frog be divided in its back, above the crural plexus, so as entirely to cut-off the nerves of the lower extremities from connection with the Brain, the animal loses all voluntary control over these limbs, and it gives no sign of pain on any injury being done to them. But they are not thereby rendered motionless; for various stimuli applied to the limbs themselves will cause movements in them. Thus if the skin of the foot be pinched, or if a flame be applied to it, the leg will be violently retracted; or if the cloaca be irritated by a probe, the feet will endeavour to push away the instrument. We have no reason hence to believe that the animal *feels* the irritation, or *intends* to execute these movements in order to escape from it; for motions of a similar kind are performed by Men who have suffered injury of the lower part of the spinal cord, and who are utterly unconscious alike of the irritation which their limbs receive and of the actions which they perform.

392. The essential participation of the Nervous System in these actions is shown by the fact, that unless the nervous trunks remain continuous with the Spinal Cord, and unless the part of the spinal cord which which they are connected remains sound (although cut-off from connection with the parts above, and with the brain), no action will result. If the trunks be divided, or *either* of the roots by which they are connected with the spinal cord be severed, or the lower portion of the spinal cord itself be injured, no stimulation will cause the muscular movements just described.

393. The class of actions thus performed is termed *reflex*; and we see that every such action involves the following series of changes. In the first place, an impression is made upon the extremity of a nerve by some external agent, just as when sensation is to be produced. Secondly, this impression is transmitted by a nervous trunk to the spinal cord in Vertebrata, or to some

ganglionic centre which answers to it in the Invertebrata. But instead of being communicated by its means to the mind, and becoming a sensation, it immediately and necessarily excites a motor impulse; which is *reflected* back as it were to certain muscles, and by their contraction gives rise to a movement. We shall hereafter see that nearly all those movements in the animal body which are immediately connected with the maintenance of the organic functions,—such as those of respiration, deglutition (or swallowing), the expulsion of the fæces, urine, fœtus, &c.,—are performed in this manner.

394. Now there is strong reason to believe that the changes which take-place in the nervous trunks are of the same nature, whatever may be the source from which they proceed,—whether, for example, the movement be simply Reflex, whether it proceed from a mental Emotion, or whether it be executed in obedience to an act of the Will. It was formerly supposed that all the *afferent* or *centripetal* fibres pass-up to the Brain, and that all the *efferent* or *centrifugal* fibres pass-down from the same organ; the Spinal Cord being looked-upon as little else than a bundle of nerves. It is now known, however, that a large proportion of the fibres of any trunk terminate in the central organ to which that trunk at first proceeds; and that the Spinal Cord may be considered as a series of such ganglionic centres, each receiving the afferent fibres, and giving origin to the efferent, of its own segment. So, again, the nerves of Special Sense,—the olfactive, optic, auditory, and gustative,—terminate in their own ganglionic centres, which lie at the base of the brain in immediate connection with the summit of the spinal cord, and which are quite independent of the Cerebrum. The apparatus for receiving impressions, and for originating motions, is thus complete in itself; and the addition of the Cerebrum does not make any essential difference in its operations, save that this sensori-motor apparatus (as it may be termed) is made to act through its means as the agent of the mind, in addition to its functions as the instrument of the automatic movements. We shall hereafter see (CHAP. XIII.) that the difference between Instinct and Intelligence is closely connected with the development of the Cerebrum; but this organ, even in that highest grade of development which it possesses in Man, has no other connection with the sensory organs than that which it acquires through its relation with the Sensory Ganglia, and has no more power of exciting muscular movement than by playing (so to speak) upon the Spinal Cord, whose efferent fibres respond to its mandates just as they would do to the stimulus of an impression primarily acting through that organ.

395. Of the mode by which the effects of changes in one part of the Nervous system are thus instantaneously transmitted to another, nothing whatever is known. There is evidently a strong

analogy between this phenomenon, and the instantaneous transmission of the Electric power along good conductors; but the relation is much more intimate than this, for Electricity is capable of exciting Nerve-force, whilst, conversely, Nerve-force can excite Electricity. Thus, a very feeble galvanic current transmitted along a motor nerve serves to excite contractions in the muscles supplied by it; and in like manner, a galvanic current transmitted along any of the sensory nerves gives rise to a sensation of the kind to which that nerve ministers. Moreover, we shall hereafter see that certain animals are capable of generating Electric power in a very remarkable manner (CHAP. XI.), and that the Nervous force is essentially concerned in this operation. But, on the other hand, it seems probable that the influence transmitted along the nerves of the living body is something different from ordinary electricity; for a nerve remains capable of conveying the influence of electricity when it has been rendered unable to transmit the influence of the brain, as by tying a ligature around it, or by tightly compressing it between the forceps, which gives no interruption to the one agency, whilst it completely checks the other. Notwithstanding, then, the strong *analogy* which exists between these two powers, we are not warranted in regarding them as *identical;* but they have towards each other that relation of reciprocity which exists between Electricity and Heat, or between Electricity and Magnetism, each being convertible into the other in a certain definite ratio (§ 48).

396. It is not by Electricity only that Nerve-trunks and the ganglia with which they are connected may be made to take-on that *active* condition which manifests itself in characteristic effects, —sensation or muscular motion. Mechanical and Chemical stimuli applied to the trunks in such a manner as to produce a change in their molecular condition, bring about the same results; but whatever be the nature of the stimulus that acts on the nerve, and however energetic its operation, neither sensation nor motion is produced by it when the passage from one grade to another is extremely gentle. Thus, when a continuous Electric current is directed along the course of a motor nerve, muscular contraction ordinarily occurs at the moment of closing and opening the circuit, whilst none usually takes place during the passage of the current, unless its intensity should undergo a sudden change either by increase or decrease. So, again, if mechanical pressure be very gradually applied to a motor nerve, its force may be steadily and continuously augmented until the nerve is killed at that spot, without the supervention of contractions in the muscles it supplies; though a much smaller amount of molecular disturbance suddenly produced, as when a nerve-trunk is violently extended, is sufficient to call-forth powerful muscular contractions. In like manner, the sudden application of Heat to nerve-trunks

may produce sensory or motor changes; whilst a more gradual change to the same absolute degree seems to have no such effect. Extremes of heat or cold destroy the vitality of nerves; and the same effect is produced by strong Chemical agents.

397. It has been ascertained by the experiments of Prof. Helmholtz, that for the transmission of impressions along Nerve-trunks in the living body, an appreciable *time* is required. The rate of transmission he estimated in the Frog at from 81 to 126 feet per second, and in Man at somewhat more than 200 feet per second. There is reason to think that the rate may be affected to a certain extent by the strength of the excitation.—The conducting power of nerve-fibres appears to persist with little decrease for some time after death, especially in cold-blooded animals; for we can, by pinching, pricking, or otherwise stimulating the motor trunks, give-rise to contractions in the muscles supplied by them, exactly as during life. This power is much lessened by the influence of narcotics; so that if a nervous trunk be soaked in a solution of opium, belladonna, or other powerful narcotic, it ceases to be able to convey the effects of stimuli to the muscle, some time before the muscles themselves lose their contractile power. On the other hand, it seems to be exalted by various irritating influences; so that when the nervous trunk has been treated with strychnia, or when it has been subjected to undue excitement in other ways, a very slight change is magnified (as it were) during its transmission, and produces effects of unusual intensity.

398. Now although the conducting power of the fibrous structure will continue for a time after the circulation through it has ceased, the peculiar endowments of the Vesicular substance, by which it *originates* the changes transmitted by the former, are *only* manifested when blood is moving through its capillaries. Thus if the circulation through the Brain cease but for a moment, total insensibility and loss of the power of voluntary motion immediately supervene. The brain is supplied with blood through four arteries,—the two internal carotids, and the two vertebrals; and by the communication of these with each other through the 'Circle of Willis,' the circulation will still be kept-up if only one of them should convey blood into the cavity of the cranium. Hence it is necessary that the flow of blood should be checked through *all* of them, in order that the functions of the brain should be suspended; and the suspension is then complete and instantaneous. The best method of effecting this was devised by Sir Astley Cooper. He tied both the carotid arteries in a dog; which operation, for the reason just mentioned, did not produce any decided influence on the functions of the brain, the circulation being kept-up through the vertebrals. But upon compressing the latter so as to suspend the flow of blood through them, *immediate* insensibility and loss of voluntary power were the result.

When the compression was taken-off, the animal immediately returned to its usual state; and again became suddenly insensible when the pressure was renewed. Although the functions of the Brain were thus suspended, those of the Spinal cord were not; as was shown by the occurrence of convulsive movements. But in the state called *Syncope*, or fainting, the suspension of the circulation by failure in the Heart's action causes an entire loss of power in both these centres; and a complete cessation of muscular movement is the result. This condition may come-on instantaneously, under the influence of powerful mental emotion, or of some other cause which acts *primarily* in suspending the Heart's action, and consequently in checking the circulation; the insensibility and loss of muscular power are *secondary* results, depending upon the suspension of the power of the Nervous centres consequent upon the cessation of the flow of blood through them.

399. The due activity of the Vesicular nervous matter is not only dependent upon a sufficient supply of blood, but it requires that this blood should be in a state of extreme purity; for there is no tissue in the body whose functions are so readily deranged by any departure from the regular standard in the circulating fluid,—whether this consist in the alteration of the proportions of its normal ingredients, or in the introduction of other substances which have no proper place in it. One of the most fertile sources of disturbance in the action of the Brain, consists in the retention of substances within the blood which ought to be excreted from it. We shall hereafter see that three of the largest and most important organs in the body,—the lungs, the liver, and the kidneys,—have it for their special office to separate from the circulating fluid the products of the decomposition which is continually taking-place in the body, and thereby to maintain its purity and its fitness for its important functions. Now if these, from any cause, even partially fail in their office, speedy disturbance of the functions of the Nervous centres is the result. Thus if the Lungs neither purify the venous blood from its impregnation with carbonic acid, nor restore to it the proper proportion of oxygen, the functions of the brain are seriously affected. The sensations become indistinct, the will loses its control over the muscles, giddiness and faintness come-on, and at last complete insensibility supervenes. Corresponding symptoms occur, though to a less serious degree, when the excretion of carbonic acid is but slightly impeded. Thus when a number of persons are shut-up in an ill-ventilated apartment, for a sufficient length of time to raise the proportion of carbonic acid in the air to 1 or 2 per cent., the continued purification of their blood by Respiration is but insufficiently performed, the reasons which will be stated hereafter (CHAP. IX.); and the carbonic acid accumulates in their blood, in a sufficient degree to produce headache and obtuseness of the

mental powers.—Similar results take-place, as will be shown in its proper place (CHAP. X.), from the retention of the substances which ought to be drawn-off by the Liver and Kidneys; these, when they accumulate in even a trifling degree, produce torpor of the functions of the brain; and when their proportion increases, complete cessation of its power is the result, their action being precisely that of narcotic poisons. Various substances introduced into the blood may exert similar influences; depressing the activity of the vesicular substance of the nervous centres, and consequently producing torpidity, not merely in the reception of impressions and the performance of voluntary motions, but also in the mental operations generally.

400. On the other hand, various conditions of the blood, especially those depending on the presence of certain toxic agents, produce an undue energy in the functions of the nervous centres; which energy, however, is almost invariably accompanied by irregularity or want of balance among its different actions. Of this we have a familiar example in the operation of Alcohol. Its first effect, when taken in moderate quantity, is usually to produce a simple increase in the activity of the Cerebral functions. A further dose, however, occasions not merely an increase, but an irregularity; destroying that power of self-control which is so important a means of balancing the different tendencies in the healthy condition of the mind. And a still larger dose has the effect of a narcotic poison; producing diminution or suspension of activity in all the functions of the brain. In some persons, this is the mode in which the alcohol acts from the first, its stimulating effects being altogether wanting.—A similar activity is usually produced by the respiration of Nitrous Oxide; which seems to increase all the powers of the mind, save that of self-control, which it diminishes; the individual, while under its influence, being the slave of his impulses, which act on his muscular system with astonishing energy.—Strychnia, again, has a most remarkable stimulating effect upon the vesicular substance of the Spinal Cord; aud a corresponding state, in which violent convulsive actions are excited by the most trifling causes, sometimes presents itself as a peculiar form of disease, named Tetanus, which may be either *idiopathic*, depending probably upon a disordered condition of the blood, or *traumatic*, consequent upon the irritation of a wound.

401. But, as formerly remarked, it is not in the Nervous *centres* only that changes originate. Whenever an impression is made upon the surface of the body, or upon the organs of special sense, which, being conducted to the nervous centres, either excites a sensation in the Brain (§ 389), or a reflex action through the Spinal cord (§ 391), the reception and propagation of such impression at the *extremities* of the sensory nerves requires a set of

conditions of the same kind with those which we have seen to exist in the nervous centres. In fact, if we regard the course of the *motor* nerves as commencing in the nervous centres and terminating in the muscles, we may with equal justice consider that of the *sensory* nerves as originating in their peripheral extremities, and terminating in the sensorium. Now it is easily shown that the circulation of blood through the peripheral origins of the sensory nerves is just as necessary for the original reception of the impressions, as is the circulation through the brain to their reception as sensations and to the origination of motor impulses by an act of the will. We find that anything which retards the circulation through a part supplied by sensory nerves, diminishes its sensibility; and that if the flow of blood be completely stagnated, entire insensibility is the result. A familiar example of this is seen in the effects of prolonged cold; which, by diminishing, and then entirely checking, the flow of blood through the skin, produces first numbness and then complete insensibility of the part. This result, however, may be partly due to the direct influence of the cold upon the nerve-vesicles themselves; depressing their peculiar vital powers (§ 97). The same effect is produced, however, when the supply of blood is checked in any other way; as, for example, by pressure on the artery, or by obstruction in its interior. Thus when the main artery of a limb is tied, numbness of the extremities is immediately perceived; and this continues until the circulation is re-established by the collateral branches, when the usual amount of sensibility is restored.

402. On the other hand, increased circulation of blood through a part produces exaltation of its sensibility; that is, the ordinary impressions produce changes of unusual energy in its sensory nerves. This is particularly evident in the increased sensibility of the genital organs of animals during the period of heat; and in those of Man when in a state of venereal excitement. Moderate warmth, friction, exercise, and other causes which increase the circulation through a part, also augment its sensibility; and this augmentation is one of the most constant indications of that state of *determination of blood* or *active congestion*, which usually precedes inflammation, and which exists in the parts surrounding the centre of inflammatory action.

403. The functional activity of the Nervous System as a whole is peculiarly liable to be depressed by the *shock* arising from sudden and severe injuries. A part of this depression is doubtless due to the enfeeblement of the circulation occasioned by the diminution of the Heart's contractility (§ 359). But this by no means accounts for the whole effect; and we find, moreover, that local suspension of nervous power may be produced by local influences which do not seriously affect the heart's action; whilst on the other hand, the functional activity of a nerve-trunk thus

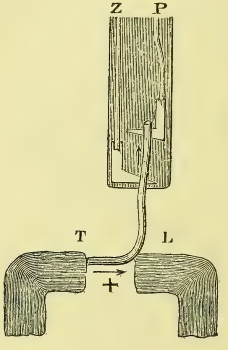
suspended may return, after repose, though the circulation be not renewed. Thus it is remarked by Dr. Dalton, that "it will often be found, on preparing the Frog's leg for experiment, that immediately after the limb has been separated from the body and the integument removed, the nerve is destitute of irritability, its vitality being suspended by the violence inflicted in the preparatory operation: in a few moments, however, if kept under favourable conditions, it recovers from the shock, and regains its natural irritability."—This general fact should be carefully borne in mind in interpreting the results of experiments on the Nervous System; for it will often be found that the first effects of the section of a nerve-trunk, or of the removal of a particular portion of the nervous centres, are to be attributed rather to the general *shock* of the operation, than to the special effect of the lesion, which can only be rightly estimated after the effects of the shock have been recovered from. Thus, for example, it was at one time maintained that the action of the Heart is dependent upon the Spinal Cord, because it is brought to a stand by passing a rod down the spinal canal, so as to break-up the neural axis: but it is now known that the entire spinal cord may be removed by successive portions, without any suspension of the heart's activity. In the same manner, it was long taught that section of the Pneumogastric nerves suspends the secretion of Gastric juice; but it is now known that this suspension is only temporary, the digestive power being recovered after a time, if the animal survive the other effects of the operation.

404. Much attention has recently been given to the Electric state of Nerves, both in their passive condition and when excited to action; and to the influence of Electric currents on their functional activity. Certain general facts may now be considered as well ascertained; but in regard to others there is so much discrepancy among different experimenters, that the Student's attention cannot as yet be profitably directed to them.—It has been clearly proved by the researches of M. du Bois-Reymond, that an electric current exists in Nerve-trunks, as in Muscles, whilst they are altogether passive. For when a small piece of a nerve-trunk is cut out of the recently-killed body of a Frog, and is so placed upon the electrodes of a delicate Galvanometer as to touch one of them with its surface and the other with its transverse section, a considerable deflection of the index is produced, marking the passage of a current from the interior to the exterior of the trunk. There is no difference between the motor and the sensory nerves in regard to the direction of the current; and there is no evidence of the passage of a current along the course of the nerve-trunks. This 'nervous current,' like the muscular, must be considered as a *derived* current; that is, as the general resultant of a number of

far more intense currents circulating in the interior of the nerve-trunk around its ultimate particles, every one of which seems to be an independent centre of electro-motor action, and to contain within itself both positive and negative elements. Very sudden and extensive variations may be produced in this nervous current by various agencies—mechanical, chemical, or thermal,—which affect the molecular condition of the nerve; and such disturbances are coincident with changes in its functional activity. Thus, if a piece of hot metal be brought near the nerve-trunk without touching it, the nervous current diminishes rapidly, and may even undergo a reversal of its direction, its property of conveying irritation to the muscle being at the same time impaired, though not destroyed; but if the nerve-trunk be then placed between muscles, so as to recover its usual moisture, it will at the same time regain its usual electro-motive power, and will again exert its ordinary action upon the muscles to which it is distributed.

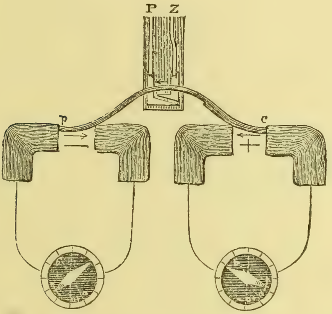
405. In investigating the effect produced upon the 'nervous current' by exciting the nerve-trunk to functional activity, it is found convenient to employ Electricity itself as the stimulus, no other being so powerful or so manageable. And it is not difficult, by a proper mode of experimenting, to prevent the electric current from producing any other influence upon the Galvanometer, than that which it exerts through the modification it induces in the proper nervous current. Thus if a portion of nerve-trunk be so placed (Fig. 113) that it touches one of the electrodes by its transverse section (which may be designated T), and the other by its surface or longitudinal section (L), and a portion of its continuation be included in a galvanic circuit, so that a current shall pass along the portion of the trunk which rests on the points connected with Z and P, this current will not exert any influence of its own upon the Galvanometers connected with the two points T and L; but it will modify the proper nervous current of the part included between those points, producing what is termed the *electrotonic* state in that portion of the trunk. If the *exciting* current between Z and P be

Fig. 113.



the same in its direction as that between T and L, then the intensity of the nervous current will be *increased*, or the electrotonic state will be *positive;* but if the exciting current pass from P to Z, or in a direction *contrary* to that of the nervous current between T and L, then the latter will be *diminished*, or the electrotonic state of that part of the trunk will be *negative*. The same 'exciting' current may be made to produce the positive phase in one part of a nerve-trunk, and the negative phase in another. For if the two extremities of a nerve (Fig 114, *p* and *c*) be so connected with two Galvanometers, that both shall develope the nervous

Fig. 114.



current between their transverse sections and their surfaces, and an intermediate portion be excited by the transmission of an electric current in the direction Z—P, the nervous current from the extremity *c* will be increased in intensity, whilst that from *p* will be diminished. — The intensity of the electrotonic condition is found to be materially affected by the distance at which the nerve is examined from the point at which the exciting current is applied, being always greater as it is nearer to that point; and it is also proportional to the intensity of the exciting current, immediately ceasing when the circuit of that current is broken. It is to the induction of the electrotonic state in the nerve supplying it, that the coutraction of the muscle is due which takes place on the completion of the circuit; and it is on the cessation of that state, that the muscular contraction depends which is consequent upon the interruption of the circuit.—When, on the other hand, a nerve is 'tetanized' by passing through it an interrupted and alternating

current (as that of a Magneto-electric apparatus), the effect is, as in the case of Muscle, to produce a diminution of its own proper current; and this condition is shown also by nerves tetanized in other ways, as by the use of strychnia.*

* A summary of the results of the further investigations of Eckhard, Pflüger, and other experimenters upon this difficult subject, will be found in the Author's "Human Physiology," 6th Edit., pp. 478—491. The Lectures of Dr. Bland Radcliffe "On Certain Disorders of the Nervous System," combine an excellent account of the enquiries of others with the results of his own ingenious researches; and develope the application of his views to the Pathology of Epilepsy and other Convulsive disorders.

BOOK II.

SPECIAL PHYSIOLOGY.

CHAPTER V.

OF FOOD, AND THE DIGESTIVE PROCESS.

1. *Sources of the Demand for Aliment.*

406. The dependence of all Organized beings upon Food or Aliment, must be evident from the facts stated in the preceding portion of this Treatise. In the first place, the germ requires a large and constant supply of material for its development into the perfect being. In all but the lower tribes of Plants, we find that the materials required for the earliest stages of this process have been prepared and set-apart by the parent. Thus in the *seed*, the germ itself forms but a small proportion of the whole substance, the principal mass being composed of albuminous and starchy matter, which is laid-up there for its nutrition; and the act of germination consists in the appropriation of that nutriment by the germ, and the consequent development of the latter, up to the point at which it becomes independent of such assistance, and is able to procure for itself, from the soil and atmosphere that surround it, the materials for its continued growth. So in the *egg* of the Animal, the principal mass is composed of Albumen and oily matter, the germ itself being at the time the egg is first deposited a mere point invisible to the naked eye; these materials serve as the food or aliment of the germ, which gradually draws them to itself, and converts them into the materials of its own structure; and at the end of a certain period the young animal comes-forth from the egg, ready to obtain for itself the food which is necessary for its continued increase in size.

407. In many instances among the lower tribes, the form in which the young animal emerges from the egg is very different from that which it is subsequently to assume; and the latter is only attained by a process of *metamorphosis*. This change has been longest known and most fully studied in the case of Insects and Frogs, which were formerly thought to constitute an exception to all general rules in this respect,—the Insect coming-forth from the egg in the state of a Worm, and the Frog in the condition of a

Fish. But it is now known that changes of form, as complete as these, occur in a large proportion of the lower tribes of Animals; so that the *absence* of them is the exception. The fact seems to be that the supply of nutriment laid-up within the egg, among the lower classes, is by no means sufficient to carry-on the embryo to the form it is subsequently to attain; and its development is so arranged that it may come into the world in a condition which adapts it to obtain its own nutriment, and thus to acquire for itself the materials for its further development. Thus the Insect, in its *larva* or Caterpillar state, is essentially a fœtus in regard to its grade of development; but it is a fœtus capable of obtaining its own food. In this condition it attains its full growth as regards *size*, without any alteration in its *form* or general condition; but it then, in passing into the Chrysalis state, reassumes (as it were) the condition of an embryo within the egg,—the development of various new parts takes-place at the expense of the nutriment stored-up in its tissues,—and it comes-forth as the perfect Insect. In many of the lower tribes, the animal quits the egg at a still earlier period in comparison; thus some of the long Marine Worms consist only of a single segment, forming a kind of head, when they leave the egg; and the other segments, to the number (it may be) of several hundred, are gradually developed from this by a process that resembles the budding of Plants.

408. Up to the period, then, when the full dimensions of the body have been attained, and the complete evolution of all its organs has taken-place, a due supply of food is necessary for these purposes. In the Plant, nearly the whole of the alimentary materials taken into the system are thus appropriated; the extension of its structure going-on almost indefinitely, and the waste occasioned by decay being comparatively small. Thus the carbon which is given out by the respiratory process in the form of carbonic acid, bears but a small proportion to that which is introduced by the decomposition of that same gas under the influence of light (§ 82). And the fall of the leaves, which takes-place once a year or more frequently, and which gives-back a large quantity of the matter that has undergone the organizing process, does not occur until by their means a considerable addition has been made to the solid and permanent substance of the tree.

409. This is not the case, however, with the Animal. Its period of *increase* is limited. The full size of the body is usually attained, and all the organs acquire their complete evolution, at a comparatively early period. The continued supply of food is then required, not for the extension of the structure, but simply for its maintenance; for in proportion to the amount of Nervo-Muscular energy which it is caused to put-forth, will there be a loss of substance in the organism, which food is needed to make good. That energy, in fact, can only be sustained by the

retrograde metamorphosis either of the Tissues of which the apparatus is composed, or of organic compounds contained in the Blood: how far each contributes is at present uncertain, but probably both have a share in the result, which will be the same in either case as regards the demand for food created by this metamorphosis. Hence a diet which would be superfluous and injurious to an individual of inert habits, is suitable and beneficial to one who is leading a life of continual exertion; and this difference manifests itself in the requirements of the same individual who makes a change in his habits,—the indolent man acquiring an appetite by vigorous exertion, and the active man losing his disposition to hearty feeding by any cause that keeps him from his accustomed exercise. We see precisely the same contrast between Animals of different tribes, whose natural instincts lead them to different modes of life. The Birds of most active flight, and the Mammals which are required to put-forth the greatest efforts to obtain their food, need the largest and most constant supplies of nutriment; but even the least active of these classes stand in remarkable contrast with the inert Reptiles, whose slow and feeble movements are attended with so little waste, that they can sustain life for weeks and even months with little or no diminution of their usual activity, without a fresh supply of food.

410. The loss of substance just adverted-to, however, does not affect the Muscular and Nervous tissues alone; for all the operations of Nutrition involve it to a certain extent, so that a renewal of the various parts of the apparatus of Organic life is required, at a rate proportional to the functional activity it is called on to put-forth. The death and decay of certain parts of the organism which are concerned in the preparation of the material for the more elaborate parts of the fabric, seems to be as necessary in the Animal as it is in the Plant (§ 408); the only essential difference being that instead of one general exuviation of these preparatory organs (the leaves), there is continually taking place an internal exuviation of more limited extent. Thus the Epithelium of the Mucous Membranes, and of the Glandular follicles prolonged from them, seems to be continually thrown-off and renewed; and the life of many of the cells concerned in the elaboration of the nutritive material seems to be of very limited duration.

411. There is another point of view in which we may consider the demand for nutriment; namely the supply which it affords not only of *material*, but of *force*. All the Organic compounds which serve as aliment, when re-converted by oxygenation into the Water, Carbonic Acid, and Ammonia from which they were at first derived (§ 197), set free in this retrograde metamorphosis a certain measure of *energy*, which may manifest itself either as Heat or under some other form. Now there is strong reason to

believe that this energy may be applied in the living body to the endowment of other portions of the same material with more elevated forms of force; the *descent* of one part thus being made to *raise* another to a higher level. Thus in the germinating seed we find that a considerable amount of Starch is changed, first into Sugar, and then into Carbonic Acid and Water, whilst Albuminous matter is being converted into organized tissue. And, in the Animal which has completed its growth, we find that a much larger quantity of nutriment is required to keep-up its full weight, than is equivalent to the loss of substance it undergoes day by day when kept altogether without food (§ 633),—the *retrograde* metamorphosis of one portion of the aliment being apparently a condition of the *progressive* metamorphosis of that other portion which is converted into organized tissue.

412. We may observe a marked difference, however, between the amount of aliment required, and the amount of waste occasioned, by the simple exercise of the *nutritive* or *vegetative* functions in the building-up and maintenance of the animal body, and that which results from the exercise of the *animal* functions. The former are carried-on, with scarcely any intermixture of the latter, during fœtal life. The aliment in a state of preparation is introduced into the fœtal vessels, and is conveyed by them into the various parts of the structure which is developed at its expense. The amount of *waste* is then very trifling, as we may judge by the small amount of excretory matter, the product of the action of the liver and kidneys, which has accumulated at the time of birth; although these organs have attained a sufficient development to act with energy when called-upon to do so. But as soon as the *movements* of the body begin to take-place with activity, the waste increases greatly; and we even observe this immediately after birth, when a large part of the time is still passed in sleep, but when the actions of respiration involve a constant employment of muscular power.—In the state of profound *sleep*, at subsequent periods of life, the vegetative functions are performed with no other exercise of the animal powers than is requisite to sustain them; and we observe that the waste and the demand for food are then alike diminished to a very low point. This is well seen in many animals which lead a life of great activity during the warmer parts of the year, but which pass the winter in a state of profound sleep, without, however, any considerable reduction of temperature (§ 121); the demand for food, instead of being frequent, is only felt at long intervals, and the excretions are much reduced in amount. And those animals which become completely inert, either by the influence of cold (§ 136), or by the drying-up of their tissues (§§ 159, 161), do not suffer from the prolonged deprivation of food; because not only are their animal functions suspended, but their nutritive operations also are in complete abeyance; and the

continual decomposition of their tissues which would otherwise be taking-place, is checked by the cold or desiccation; so that the whole series of changes which goes-on in their active condition, is brought completely to a stand.

413. But there is another most important cause of demand for food, amongst the higher Animals, which does not exist either amongst the lower Animals, or in the Vegetable kingdom. We have seen (CHAP. II, Sect. 2) that Mammals and Birds, and to a certain extent Insects also, are able to sustain the heat of their bodies at a fixed standard, and thus to become independent of variations in external temperature. This they are enabled to do, as will be explained hereafter (CHAP. XI), by a process strictly analogous to ordinary combustion; the Carbon and Hydrogen which are directly supplied by their food, or which have been employed for a time in the composition of the living tissues and are then set-free, being made to unite with Oxygen introduced by the Respiratory process, and thus giving-off as much heat as if the same materials were burned in a furnace. And it has been further shown that the immediate cause of death in a warm-blooded animal from which food has been entirely withheld, is the inability any longer to sustain the temperature which is requisite for the performance of its vital operations (§ 117). Hence we see the necessity for a constant supply of aliment, in the case of warm-blooded animals, for this purpose alone; and the demand will be chiefly regulated by the external temperature. When the heat is rapidly carried-off from the surface by the chilling influence of the surrounding air, a much greater amount of Carbon and Hydrogen must be consumed within the body to maintain its proper heat, than when the air is nearly as warm as the body itself; so that a diet which is appropriate to the former circumstances is superfluous and injurious in the latter, while the food which is amply sufficient in a warm climate is utterly destitute of power to enable the body to resist the influence of severe cold. This is a fact continually experienced both in the ordinary recurrence of changes of temperature in our own climate, and still more remarkably when the same individual is subjected to the extremes of heat and cold, in successively visiting the tropical and frigid zones.

414. Thus we find that in the Animal body, aliment is ordinarily required for four different purposes. *First*, for the original construction or building-up of the organism. *Second*, to supply the loss occasioned by the vital actions required for its maintenance even when in a state of repose. *Third*, to compensate for the waste occasioned by the active exercise of the nervous and muscular systems. And *Fourth*, to supply the materials for the heat-producing process, by which the temperature of the body is kept up.—The amount required for these several purposes will

vary according to the conditions of the body, as regards exercise or repose, and external heat or cold. It is also subject to great variation with difference of *age*. During the period of growth it might be anticipated that a larger supply of food would be required, than when the full stature has been attained; yet a very small daily addition would suffice in the case of a child or youth to produce the entire increase of a whole year. But every one knows that the child requires *much* more food than the adult, in proportion to his comparative bulk. This results from the much more rapid *change* in the constituents of his fabric, which is evident from the large proportional amount of his excretions, from the quickness with which the effects of illness or of deficiency of food manifest themselves in the diminution of the bulk and firmness of the body, from the short duration of life when food is altogether withheld, and from the readiness with which losses of substance by disease or injury are repaired, when the nutritive processes are restored to their full activity. The converse of all this holds good in the aged person. The excretions diminish in amount, the want of food may be sustained for a longer period, losses of substance are but slowly repaired, and everything indicates that the interstitial changes are performed with comparative slowness; and, accordingly, the demand for food is far less in proportion to the bulk of the body than it is in the adult, and may be even absolutely less than in the child of a fourth of its weight.

415. The demand for food is increased by any cause which creates an unusual *drain* or *waste* in the system. Thus an extensive suppurating action can be sustained only by a large supply of highly nutritious food. The mother, who has to furnish the daily supply of milk which constitutes the sole support of her offspring, needs an unusual sustenance for this purpose. And there are states of the system in which the solid tissues seem to possess an unusual tendency to decomposition, and in which an increased supply of aliment is therefore required. This is the case, for example, in Diabetes; one of the first symptoms of which disease is the craving appetite that seems as if it would never be satisfied. And there can be no doubt that, putting aside all the other circumstances which have been alluded-to, there is much difference amongst individuals, in regard to the rapidity of the changes which their organism undergoes, and the amount of food required for its maintenance.

416. The influence of the supply of Food upon the size of the individual is very evident in the Vegetable kingdom; being most strikingly manifested when a plant naturally growing in a poor dry soil is transferred into a damp rich one, or when we contrast two or more individuals of the same species growing in localities of opposite characters. Thus says Mr. Ward, "I have gathered,

on the chalky borders of a wood in Kent, perfect specimens in full flower of *Erythræa Centaurium* (Common Centaury), not more than half an inch in height, consisting of one or two pairs of most minute leaves, with one solitary flower; these were growing on the bare chalk. By tracing the plant towards and in the wood, I found it gradually increasing in size, until its full development was attained in the open parts of the wood, where it became a glorious plant, four or five feet in elevation, and covered with hundreds of flowers."—On the other hand, by starvation naturally or artificially induced, Plants may be dwarfed or reduced in stature: thus the Dahlia has been diminished from six feet to two; the Spruce Fir from a lofty tree to a pigmy bush; and many of the trees of plains become more and more dwarfish as they ascend mountains, till at length they exist as mere underwood. Part of this effect, however, is doubtless to be attributed to diminished temperature; which, as already remarked (§ 107), concurs with deficiency of food in producing inferiority of size.

417. Variations in the supply of food would not appear to be effectual in producing a corresponding variety of size in the Animal kingdom: this is not, however, because Animals are in any degree less dependent than Plants upon a due supply of food; but because such a limitation of the supply as would *dwarf* a Plant to any considerable extent, would be fatal to the life of an Animal. On the other hand, an excess of food, which (under favourable circumstances) would produce great increase in the size of the Plant, would have no corresponding influence on the Animal; for its size appears to be restrained within much narrower limits,—its period of growth being restricted to the early part of its life, and the dimensions proper to the species being rarely exceeded in any great degree. Even in the case of *giant* individuals, it does not appear that the excess of size is produced by an over-supply of food; but that the larger supply of food taken-in is called-for by the unusual wants of the system,—those wants being the result of an extraordinary activity in the processes of growth, and being traceable rather to the properties inherent in the organism, than to any external agencies. Thus we not unfrequently hear of children who have attained an extraordinary size at the age of a few years; and this excess of size is usually accompanied with other marks of precocious development. We shall hereafter see that a provision exists in the Digestive apparatus, which absolutely prevents the reduction and preparation of the food, in any amount greatly surpassing that which the wants of the system demand (§ 474); and it is probably to this cause, in part, that we are to attribute the small degree of influence exerted by an excess of food, in producing an increased development of the Animal frame.

418. The influence of a diminished supply of food, in producing

a marked inferiority in the size of Animals, is most effectually exerted during those early periods of growth in which the condition of the system is most purely Vegetative. Thus it is well known to Entomologists, that, whilst it is rare to find Insects departing widely from the average size on the side of excess, dwarf-individuals, possessing only half the usual dimensions, or even less, are not uncommon; and there can be little doubt that these have suffered from a diminished supply of nutriment during their larva state. The variation is most apt to present itself in the very large species of Beetles which pass several years in the larva state; and such dwarf specimens have even been ranked as sub-species. Abstinence has been observed to produce the effect, upon some Caterpillars, of diminishing the number of moults and accelerating the transformation; in such cases, the Chrysalis is more delicate, and the size of the perfect Insect much below the average.

419. One of the most remarkable examples known, of the effect of food in modifying the development of Animals, is to be found in the economy of the Hive-Bee. In every community the majority of individuals consists of *neuters*, which may be regarded as females having the organs of the female sex undeveloped, and which, whilst incapable of reproduction, perform all the labours of the hive. The office of continuing the race is restricted to the *queen;* who is the only perfect female in the community. If by any accident the queen be destroyed, or if she be purposely removed for the sake of experiment, the bees choose two or three from amongst the *neuter larvæ* which are being nurtured in their appropriate cells; and these they cause to be developed into *perfect queens*. The first operation is to change the cells in which they lie into *royal cells*, differing considerably from the ordinary ones in form, and of much larger dimensions: this is accomplished by breaking-down the walls of the surrounding cells, removing the eggs or grubs they may contain, and rebuilding the central cell upon an enlarged scale, and upon the same plan as the royal cells in which the queens are ordinarily reared. Whilst this operation is going-on, the maggot is supplied with food of a very different nature from the farina or bee-bread (composed of a mixture of pollen and honey) which has been stored-up for the nourishment of the workers; this food being of a jelly-like consistence and pungent stimulating character. After the usual transformations, the grub becomes a perfect Queen; differing from the neuter-bee, into which it would have otherwise been changed, not only in the development of the reproductive system, but in the general form of the body, the proportionate shortness of the wings, the shape of the tongue, jaws, and sting, the absence of the hollows on the thighs in which the pollen is carried, and the loss of the power of secreting wax.

420. That insufficiency of wholesome food, continued through successive generations, may produce a marked effect, not merely upon the stature, but upon the form and condition of the body, even in the Human race, appears from many cases in which such influence has operated on an extensive scale. Thus there are parts of Ireland inhabited by a population descended from those who were treated by the English as rebels two centuries since, and who were driven into mountainous tracts bordering the sea, where they have been since exposed to the two great brutalizers of the human race, hunger and ignorance. The present race is distinguished physically from the kindred race of Meath and other neighbouring districts, where the same causes have not been in operation, by their low stature (not exceeding five feet two inches), their pot-bellies and bow-legs; whilst their open projecting mouths, with prominent teeth and exposed gums, their advancing cheek-bones and depressed noses, bear barbarism in their very front. "These spectres of a people that once were well-grown, able-bodied, and comely, stalk abroad into the daylight of civilization, the annual apparitions of Irish ugliness and Irish want."—The aboriginal population of New Holland, as a whole, presents a similar aspect; and apparently from the operation of the same causes.

421. When a larger quantity of Azotized food (§ 429) is habitually consumed than the wants of the system require, it is not converted into solid flesh, but has to be got-rid-of by the various processes of excretion. The increased production of Muscular fibre depends, as we have already seen (§ 360), upon nothing so much as the exercise of the muscle. It cannot indeed take-place unless the blood supply the appropriate materials; but no degree of richness of the blood can alone produce it. Consequently the excessive accumulation of nutritive matter in the blood is so far from being a condition of *health*, that it powerfully tends to produce *disease*, either of an inflammatory or of the hemorrhagic character. The state of Plethora is most apt to present itself in those who live well and take little exercise; and the remedy for it is either to diminish the diet, or to increase the amount of exercise, so as to bring the two into harmony.

422. The continued over-supply of food has several injurious effects: it disorders the digestive processes, by stimulating them to undue activity, and lays the foundation for a complete derangement of them; it gives a predisposition to the various diseases of repletion, as just noticed; and it throws upon the excreting organs much more than their proper amount of labour, besides tending to produce a depraved condition of the matters to be drawn-off by them, which renders the proper act of excretion still more difficult. When this is the case, various disorders arise, caused by the retention, within the circulating current, of

substances which are very noxious to the general system, and which become most fertile sources of disease. What are commonly regarded as diseases of the biliary and urinary organs, are really, in a large proportion of cases, nothing else than disordered actions of those organs, occasioned by the irregular mode in which the products of decomposition are formed within the blood, and dependent upon some error in diet, either as regards quantity or quality. Thus the 'lithic acid diathesis,' in which there is an undue proportion of that substance in the urine, and of which Gout is a particular manifestation, is due, not to disorder of the kidney, but to an undue production of lithic acid in the blood. So long as the excreting action of the kidney is sufficient to prevent its accumulation in the blood, so long the general health is but little affected; but whenever that action receives a check, various constitutional symptoms indicate that the system is disturbed by the presence of this product of decomposition. And though our remedies may be rightly directed in part to facilitating its escape through the kidneys, yet the radical cure is to be sought only in the regulation of the diet, and in the limitation of the first production of the substance in question.—Similar remarks might probably be applied to disorders of the Liver; but we are, from various causes, far less perfectly acquainted with their character, than we are with those of the Kidney.

423. There is only one tissue of which the increase is directly produced by an over-supply of food: this is the Adipose or fatty. It is formed almost entirely at the expense of the non-azotized constituents of the food (§430); the walls of the cells within which the fatty matter is secreted (§ 228) being the only part of this tissue that is derived from the albuminous compounds of the blood. The production of the adipose tissue is most directly favoured by the presence of a large amount of Oleaginous matter in the food; but it may also be effected, as will be presently shown, by the conversion of Starchy and Saccharine substances into fatty compounds. It cannot occur, unless there be in the food a larger proportion of substances that can be thus appropriated, than is sufficient to maintain the heat of the system by the respiratory process: consequently whatever increases the demand for heat is unfavourable to the deposition of fat; and *vice versa.* The fattening of animals is now brought to a regular system; and experience has shown that rest and warm temperature, with food containing a large amount of oily matter, are most conducive to the accumulation. Rest acts by keeping the respiration at a low standard; for it will hereafter be shown (§§ 645, 692) that a much larger proportion of carbonic acid is thrown-off when the body is in active movement, than when it is in repose. External warmth has the same effect, the demand upon the calorifying power being diminished, and more of the combustible material being left to be stored-up as fat.

424. The deposition of Fat affords a supply of combustible matter against the time when it may be needed; and it is consequently found that the duration of life in warm-blooded animals, when they are completely deprived of food, is in great degree proportional to the amount of fat they have previously accumulated. When an animal is undergoing starvation, the heat-producing process is mainly kept-up by the store of fat, which is thus gradually consumed; and when it is completely exhausted, the temperature falls, hour by hour, until life can no longer be sustained (§ 117). The use of this store of fat, in supplying any temporary deficiency in the food, becomes evident from such experiments; for when it has been completely exhausted, the withholding of a single meal proves fatal, from the want of power to sustain the calorifying process.—We find that animals which are likely to suffer from deficiency of food in the winter, or which spend that period in a state of quiescence, have a tendency to accumulate a store of fat in the autumn; which tendency seems principally to depend upon the nature of their food. We observe it chiefly in those Birds and Mammals which live upon seeds and grains; and these, when ripe, contain a large quantity of oily matter, which thus becomes a valuable store against the time of need. There are many birds, such as the becafico so much esteemed in Italy, which are described, if killed at this season, as being "lumps of fat."

425. It is well known to breeders of cattle, that some varieties or breeds have a much greater tendency to the production of Adipose tissue, than others placed under the same circumstances; and the former are therefore selected to undergo the fattening process. Corresponding differences may be met-with among different individuals of the Human race; some persons having a remarkable tendency to the production of fat under circumstances which do not seem by any means favourable to it, whilst others appear as much indisposed to this deposit. Where it becomes excessive, it may be kept under by such an alteration in the diet as will exclude as far as possible either fatty matter or substances capable of being readily converted into fatty matter (§ 430); and at the same time the amount of exercise should be increased, so that all superfluous matters of this kind may be eliminated by the additional respiration which then takes-place.

426. We see, then, that the amount of food which can be properly appropriated by the system, varies considerably in different individuals, and in the same individual under different circumstances. Consequently it is impossible to give any general rule, which shall apply to every one alike. The *average* quantity required by adult men, leading an active life, and exposed to the ordinary vicissitudes of temperature in our own climate, seems to be from 30 to 36 ounces of *dry* aliment. But if the muscular

powers are but little exerted, and the surrounding temperature be high, a healthy condition may be kept-up on scarcely more than half this allowance: provided that it consist of substances of a nutritious kind, united in proper proportions.

427. The alimentary value of different substances depends in the first place upon the quantity of solid matter they contain; being of course greater as the solids form a larger proportion of the entire weight. Many esculent vegetables contain so large a quantity of water, that the nutriment they afford is very slight in proportion to their bulk; and even in animal flesh, only about one-fourth consists of solid matter, the remainder being water.—Next it depends upon the proportion of digestible matter which the solid parts include; for it is not every substance containing the requisite ingredients, that is capable of being reduced to a state which enables it to be absorbed. Thus woody fibre has the same elementary composition as starch-gum; but it passes-out of the intestinal canal unchanged, and therefore affords no nutriment. In the same manner, the horny tissues of animals, though nearly allied to albumen in their composition, are completely destitute of nutritive properties to Man and the higher animals, because not capable of being reduced by their digestive process; though certain Insects appear capable of living exclusively upon them.

428. But when the watery and indigestible parts of the food are put out of consideration, and our attention is directed only to the soluble solids, we find a most important difference in the chemical composition of different substances, which renders them more or less appropriate to the different purposes which have to be answered in the nutrition of the body. It has been already pointed-out, that Vegetables possess the power of combining the *elements* furnished by the inorganic world into two classes of Organic compounds,—the ternary, consisting of oxygen, hydrogen, and carbon,—and the quaternary, which consist of these elements with the addition of azote or nitrogen. These two classes are hence termed the *non-azotized*, and the *azotized*.

429. Now the Azotized compounds are required for the reparation of the waste of the nervous and muscular tissues, and for the general nutrition of the body; consequently, unless the food contain a sufficient proportion of these substances, the body must be insufficiently nourished and the strength must diminish, even though other elements of the food be in superabundance. The azotized substances formed by Plants are essentially the same, as already shown (§ 179), with those which are furnished by the Albuminous solids and fluids of Animals; but the quantity of them is usually small in proportion to the non-azotized, being considerable only in the Corn-grains, in the seeds of Leguminous plants, and in some other products, which the universal experience

of ages has demonstrated to be the most nutritious of Vegetable substances. The other azotized compounds existing in the animal body, may be elaborated by the transformation of these albuminoid compounds; so that when *they* are duly supplied, the system cannot become enfeebled for want of support.—But there is another azotized compound, Gelatin, that is procurable from the tissues of Animals, to which nothing analogous exists in Plants; and this is commonly reputed to possess highly nutritious properties. It may be confidently affirmed, however, as the result of experiments made upon a large scale, that Gelatin is incapable of being converted into Albumen in the animal body, so that it cannot be applied to the nutrition of the albuminous tissues. And although it might *a priori* be thought not unlikely, that Gelatin taken-in as food should be applied to the nutrition of the gelatigenous tissues (§ 194), yet neither observation nor experiment bears-out such a probability. For, on the one hand, the study of the development of these tissues leads to the conclusion that they have their origin, like those whose constitution is albuminous, in the plasma of the blood, which does not contain gelatin; whilst, on the other, the introduction of gelatin into the blood is speedily followed by such a large increase in the excretion of urea, as renders it almost certain that this substance must have undergone decomposition in the system, so as to be removed from it by the action of the lungs and kidneys. Consequently, the use of Gelatin as food would seem to be limited to its power of furnishing a certain amount of combustive material which may assist in maintaining the heat of the body; and there is this advantage in combining a proportion of gelatin with the diet,—especially when the digestive powers are feeble,—that being already in a state of perfect solution, it is taken-up at once by the simple act of physical absorption or endosmose, instead of requiring any exertion of vital activity to prepare it for absorption.

430. The Non-azotized compounds, which are presented to us in great abundance in the Vegetable kingdom, exist under various forms; of which the principal are Starch, Sugar, and Oil. The two former may be regarded as belonging to one class, the *Amylaceous;* because we know that starch and the substances allied to it may be converted into sugar by simple chemical processes (§ 171), and that this transformation takes-place readily both in the Vegetable and Animal economy. On the other hand, the *Oleaginous* matters contained in vegetable and animal food are usually ranked as a distinct group of alimentary substances; and it has been maintained that under no circumstances has the Animal the power of elaborating fatty matter from starchy or saccharine compounds. But this is now known to be an unfounded limitation: since the transformation of a saccharine into a fatty compound takes-place in the case of Bees, which form wax

when fed upon pure sugar; in the fattening of animals it has been demonstrated that the addition to their weight may be much greater than the oleaginous constituents of their food would account for; and it has been further shown that such a metamorphosis may take-place in the laboratory of the Chemist, —butyric acid (the fatty acid of butter) being one of the products of the fermentation of sugar occurring under peculiar circumstances.

431. The association of Oleaginous with Albuminous matter seems to be essential in every act of nutrition. We find the two combined in the Yolk of the egg, in the Chyle, and in the organizable *blastema* exuded for the reparation of breaches of substance. And it is by no means correct, therefore, to limit the use of the non-azotized substances in the Animal economy to the maintenance of the temperature of the body by the heat which they evolve when oxidized by the Respiratory process. Still there can be no doubt that the production either of Heat or of Mechanical force by the combustive action to which they are subjected, is the purpose to which the greater part of this form of aliment is directly applied; and even that which is first converted into tissue is destined ultimately to be subjected to the like oxidation. In the compounds of the *Amylaceous* group, the proportion of Oxygen is as large as suffices to form water with the Hydrogen of the substance (§ 170); so that its Carbon is free to combine with the oxygen taken-in by the lungs, and thus becomes a source of calorifying power. But in the *Oleaginous* matters taken-in as food, the proportion of Oxygen is far smaller, so that they contain a large quantity of surplus Hydrogen, as well as of Carbon, ready to be burned-off in the system, and thus to supply the heat required (§ 176); and hence these substances are particularly valuable as articles of food, when life has to be sustained under severe external Cold.—The greatest economy in the choice of diet is therefore exercised, when it is composed of azotized substances in sufficient amount to repair the waste of the system, and of non-azotized compounds which include free carbon and hydrogen in sufficient quantity to develope (with the aid of other processes) the requisite amount of heat by combination with oxygen. But if there be a deficiency in either of these kinds of aliment, the body must suffer. Should the supply of duly-prepared azotized matter be less than is required to repair the waste of the albuminous and gelatinous tissues, then these diminish in bulk and in vital power, though the heat of the body may be kept-up to its proper standard. But if the non-azotized matter should be supplied in insufficient amount, or in a form in which it cannot be appropriated, the heat of the body cannot be sustained in any other way than by drawing upon the store of fat previously laid-up.

432. Various circumstances lead to the belief that the Saccha-

rine compounds, whether introduced as such, or formed during digestion by the metamorphosis of starch (§ 171), are thus carried off by the respiratory process within a short time after they have been introduced into the system. They have not been detected in the chyle drawn from the lacteal absorbents, but in consequence of their ready solubility they are directly taken-up by the blood (§ 492); and if the blood be examined within a short time after a meal consisting in part of farinaceous and saccharine substances, a very appreciable quantity of saccharine matter is found in it. This soon disappears, however; being eliminated or separated from the blood by the action of the lungs. In fact, it is very probable that a large proportion of the matter thus taken-in never enters the general circulation at all; since the blood of the mesenteric veins proceeds to the lungs, after passing through the liver, before it is transmitted to the systemic arteries, and may there lose its saccharine matter as fast as this is taken-in from the stomach. After a meal containing the ordinary admixture of saccharine, oily, and albuminous compounds, it is probable that the saccharine are first received into the blood, and are the first to be eliminated from it; and that, by the time *they* have been all consumed, the oily matter, introduced through the more circuitous channel of the lacteal system, is ready to answer the same purpose. If these combustive materials be exhausted before a fresh supply of food is taken-in, cold as well as hunger is experienced; and the body is in this condition peculiarly liable to suffer from any depressing causes, such as a low external temperature, poisonous miasmata, &c.; hence the prudence of avoiding exposure to such influences upon an empty stomach.

433. We can thus in part account for the fact, which universal experience has established, that, in warm-blooded animals, a mixture of azotized and non-azotized substances is the diet most conducive to the welfare of the body; and that, in all but the purely carnivorous tribes, the diet provided by Nature consists not only of albuminous, gelatinous, and oily substances, such as are furnished by the flesh and fat of animals, but also of saccharine or farinaceous matter. This is the diet to which Man is evidently best adapted; and it is remarkable how completely accordant is his use of the ordinary materials of food, with the principles now established by chemical and physiological research, in regard to the wants of his bodily system, and the best mode of supplying them. Thus, good wheaten bread contains, more nearly than any other substance in ordinary use, that proportion of Albuminous and Amylaceous compounds, which is adapted to repair the waste of the system, and to supply the necessary amount of combustive material, under the ordinary conditions of civilized life in temperate climates; and we find that health and strength can be more perfectly sustained upon that substance, than upon any other taken

alone. The addition of a moderate quantity of butter increases its heat-producing power; and this is especially useful when the temperature is low, under which condition there is usually an increased disposition to the employment of fatty matters as articles of food. The replacement of wheat by maize, which contains a considerable per-centage of oil, has been found to answer the same purpose. On the other hand, if the body be subject to violent exertion, it is found advantageous to increase the proportion of the albuminous compounds, by the addition of animal flesh; the use of this, however, as a principal article of diet, except when the individual is leading the incessantly-active life of a carnivorous animal, is very far from being economical, and is positively injurious to the welfare of the body.

434. On the other hand, in rice, potatoes, cassava-meal, and similar substances, the Amylaceous components form so very large a proportion of the whole mass, and the Albuminous compounds are present in so very small an amount, that they are insufficient to support the bodily vigour when taken alone, unless a large quantity be ingested, so as to supply the requisite proportion of azotized matter. But when these substances form part of a mixed diet, the other ingredients of which consist of animal flesh, a much smaller quantity of them suffices; and the same kind of combination is then formed, as exists in the single article of bread. Those in whose diet the farinaceous elements predominate largely, and the azotized compounds exist in the smallest amount compatible with the maintenance of the bodily vigour, are exempt from many diseases incident to those who live more highly; thus among the potato-eating Irish and the oatmeal-feeding Scotch, gout is a disease never heard of; whilst among the richer classes of the same countries there is no peculiar exemption from it.

435. The Oleaginous constituents of food are most abundant in the diet of the inhabitants of the frigid zones, who feed upon whales, seals, and other animals loaded with fat, and who devour this fat with avidity, as if instinctively guided to its use. It is by the enormous quantity of this substance taken-in by them, that they are enabled to pass a large part of the year in a temperature below that of our coldest winter, spending a great portion of their time in the open air, as well as to sustain the extreme of cold to which they are occasionally subjected. And in consequence of its being more slowly introduced into the system than most other substances, a larger quantity may be ingested at one time without palling the appetite; whilst its bland and non-irritating character favours its being retained until it is all absorbed. In this manner the Esquimaux and Greenlanders are enabled to take-in 20 or 30 pounds of blubber at a meal; and, when thus supplied, to pass several days without food.—On the other hand, among the inhabitants of warm climates, there is comparatively little disposition to

the use of oily matter as food; and the quantity of it contained in most articles of their diet is comparatively small.

436. In the Milk which is the sole nutriment of young Mammalia during the period immediately succeeding their birth, we find an admixture of albuminous, saccharine, and oleaginous substances; which indicates the intention of the Creator that all these should be employed as components of the ordinary diet. The Casein or cheesy matter is an Albuminous compound; the Butter differs but little from the ordinary fats; and its Sugar is nearly allied to Glucose. The relative amount of these ingredients in the milk of different animals is subject, as we shall hereafter see, to considerable variation; but they constantly exist, at least in the milk of the Herbivorous Mammalia, and of those which, like Man, subsist upon a mixed diet. The milk of purely Carnivorous animals, however, contains scarcely any sugar, so long as they are fed upon a purely animal diet; chiefly consisting, like their food, of albuminous compounds and fatty matter.

437. No fact in Dietetics is better established, than the impossibility of long sustaining health, or even life, upon any single alimentary principle. Neither pure albumen or fibrin, gelatin or gum, sugar or starch, oil or fat, taken alone for any length of time, can serve for the due nutrition of the body. This is partly due, so far as the non-azotized and gelatinous compounds are concerned, to their incapability of supplying the waste of the albuminous tissues. This reason does not apply, however, to the Albuminous compounds; which can not only serve for the reparation of the body, but can also afford the carbon and hydrogen requisite for the sustenance of its temperature. But even these, as we have seen, need to be associated with Fatty matter. And it is the constant result of experience that the continued use of *single* alimentary substances excites such a feeling of disgust, that the animals experimented-on seem at last to prefer starvation rather than the ingestion of them. Consequently it is quite impossible to ascertain, by such experiments, the nutritive power of the different alimentary principles; no animal being capable of sustaining life upon less than two of them at least. The same disgust is experienced by Man when too long confined to any article of diet which is very simple in its composition; and a craving for change is then experienced, which the strongest will is scarcely able to resist. Thus, in the treatment of Diabetes, a disease in which there is an undue tendency to the production of sugar in the system, it is very important to abstain completely from the introduction of saccharine or farinaceous matters in the food; but the craving for vegetable food, which is experienced when the diet has long consisted of meat alone, is such as to make perseverance in the latter very difficult; and a means has been devised of supplying this want without injury, by the use of bread from which the starchy

portion has been removed, the gluten or azotized matter alone being eaten.

438. The Organic compounds which have been enumerated as supplying the various wants of the system, would be totally useless without the admixture of those Inorganic substances, which also form a constituent part of the bodily frame, and which are constantly being voided by the excretions, especially in the Urine. Of these and their sources, however, a sufficient account has already been given (§§ 165-167).

439. It appears from enquiries into the amount of different kinds of food consumed by the ordinary labouring population in this country, that a daily average of about 5000 grains of Carbon and 216 grains of Nitrogen is absolutely required to maintain the system in health; a reduction of one-eighth being attended with a decided diminution in vigour. A well-fed man consumes about 300 grains of Nitrogen per day. Now since, according to Payen, 1000 grains of Bread contain (in round numbers) 300 grs. of Carbon and 10 of Nitrogen, a man living upon bread alone must eat 30,000 grs. (or nearly 4 lbs.) of it in order to obtain 300 grs. of Nitrogen; whilst, on the other hand, he need only eat 16,666 grs. (or but little more than half the quantity) to obtain 5000 grs. of Carbon. Hence it is obviously economical to add to a Bread diet a small quantity of Flesh, Cheese, or other highly nitrogenous food. Again, 1000 grains of Meat contain (in round numbers) 100 grs. of Carbon and 30 grs. of Nitrogen; hence a man living upon Meat alone must consume 50,000 grs. (or more than 7 lbs.) to obtain 5000 grs. of Carbon, whilst he need only eat 10,000 grs. (or one-fifth of that quantity) to obtain 300 grs. of Nitrogen. Hence when Meat is largely used, it should be combined with a considerable proportion of Amylaceous substances. About 2 lbs. of Bread with $\frac{3}{4}$ lb. of Meat will afford adequate sustenance to a healthy man under all ordinary circumstances of exertion and temperature; and this is more than is needed by such as lead sedentary lives and are but little exposed to cold.—But if the diet of Man be long restricted to Bread and Meat alone, his system becomes liable to deterioration from the want of some constituent which *fresh vegetables* alone can supply. What that essential constituent is, cannot be stated with certainty; but experience has amply demonstrated that the continued privation of fresh vegetables is almost certain to develope that constitutional disorder which is known as *scurvy*, and that nothing is so effectual as a copious supply of Vegetables and Fruits in curing that disorder when it is once established. Hence every dietary system ought to include some form of these productions; and they are most needed under circumstances in which confinement, bad ventilation, depression of spirits, or absolute insufficiency of food, are exerting, either separately or concurrently, a general depressing influence upon the vital powers.

440. The necessity of a constant supply of *Water* for the maintenance of the Animal organism, is apparent from what has already been stated (§ 165) of its uses in the economy. No other liquid can supply its place; and the deprivation of water is felt even more severely than the deprivation of food.—The extent to which *Alcohol* is used, in combination with water and with organic and saline compounds, in the various forms of 'fermented liquors,' deserves particular notice, on account of the numerous fallacies which are in vogue respecting it. In the *First* place, it may be safely affirmed that Alcohol cannot answer any one of those important purposes for which the use of Water is required in the system; whilst, on the other hand, it tends to antagonize many of those purposes, by its power of precipitating most of the organic compounds whose solution in water is essential to their appropriation by the living body. *Secondly:* The ingestion of Alcoholic liquors cannot supply anything which is essential to the due nutrition of the system; since we find not only individuals, but whole nations, maintaining the highest vigour and activity, both of body and mind, without ever employing them as an article of diet. *Thirdly:* It may be regarded as certain that Alcohol cannot be applied to the nutrition of the tissues; and it is doubtful how far it is even made subservient to the production of heat by the combustive process. The experience of Arctic voyagers is most decided in regard to the low value of Alcohol, in comparison with Fat, as a heat-producing material; and recent experimental researches have shown that a great part, if not the whole, of the Alcohol ingested is eliminated unchanged by the Lungs, Skin, and Kidneys. *Fourthly:* The operation of Alcohol upon the living body is essentially that of a *stimulus;* increasing for a time, like other stimuli, the vital activity of the body, and especially that of the nervo-muscular apparatus; but being followed by a corresponding depression of power, which is the more prolonged and severe in proportion as the previous excitement has been greater.—The results of the administration of Alcohol in large doses are so decidedly *poisonous*, and the injurious consequences of its habitual or frequent use in what is admitted to be 'excess' are so palpable, that the only sufficient justification of its habitual use in smaller quantities is to be found in clear and decided evidence of its beneficial agency. For the right estimation of this, it is essential to distinguish between the temporary exhilaration and the persistent results; and it may be stated generally that where exhilaration is produced, there is subsequent depression; and that the best effects of the use of Alcoholic beverages are seen in those cases in which they act merely in promoting the digestive and assimilating operations, so as to enable the system to appropriate the aliment it really needs, and without which its powers would fail. The best general rule for the young, the Author is convinced, is

habitual abstinence from Alcoholic beverages; and this abstinence may be persisted in with advantage through life, by those who are endowed with a constitution of ordinary vigour, and who live in accordance with the rules of health. It is for the most part under the influence of the 'wear and tear' to which those leading a life of active mental exertion in our great towns are more especially liable, that the system loses somewhat of its self-sustaining power; and experience shows that those who are subjected to this kind of depressing influence may benefit by such limited use of the weaker Alcoholic drinks (such as bitter ale, or light natural wines) as acts favourably upon the digestive power, without producing any perceptible general stimulation.

2. *Of the Digestive Apparatus and its Actions in general.*

441. It has been already pointed-out that the nature of the food of Animals is so far different from that of Plants, as to require the preparatory process of Digestion, before its nutritious part can be taken-up by the absorbent vessels and received into the system. This process may be said to have three different purposes in view; —the reduction of the alimentary matter to a fluid form, so that it may become capable of being absorbed;—the separation of that portion of it which is fit to be received into the current of the circulation, from that which does not prove to be digestible;— and the alteration, to a certain extent, when required, of the Chemical constitution of the former, which prepares it for the important changes it is subsequently to undergo. The simplest conditions requisite for the accomplishment of these purposes are the following:—a fluid capable of performing the solution, and of effecting the required chemical changes;—and a cavity or sac in which these operations may be performed.

442. We have seen how all this is accomplished in the very lowest Animals even without any definite structural arrangement (§§ 199—203): and when we pass upwards to the class of Zoophytes, we still find the digestive cavity formed upon a very simple plan; being a mere excavation in the solid tissue of the body, lined with a membrane which is an inverted continuation of the external integument, and communicating with the exterior by one orifice only, through which food is drawn-in and excrementitious matter rejected. In the little *Hydra*, or fresh-water Polype, the external covering of the body and the lining of the stomach correspond so closely in their structure,—their actions differing only with their situation,—as to be mutually convertible; for the animal may be turned completely inside-out without its functions being deranged. The fluid necessary to dissolve the food, known by the name of 'gastric fluid' or 'gastric juice,' is secreted in the walls of the stomach; and, from the transparency of the tissues,

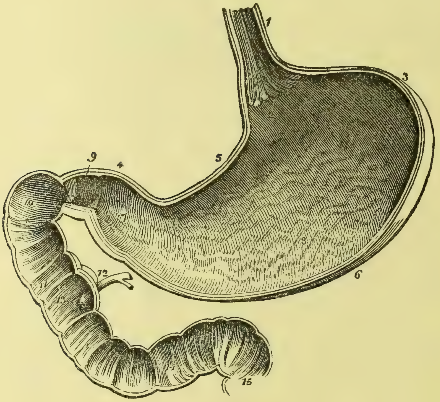
the whole process may be watched. The prey is frequently, and indeed generally, introduced alive, by the contractile power of the arms, which coil round it, and gradually draw it into the mouth or entrance to the digestive cavity; and its movements may often be observed to continue for some time after it has been swallowed. In a little while, however, its outline appears less distinct, and a turbid film partly conceals it; the soft parts are soon dissolved and reduced to a fluid state; and any firm indigestible portions which the body may contain, are rejected through the aperture by which it entered. The nutritive matter is absorbed by the walls of the digestive cavity, every part of which appears to be endowed with equal power in this respect; and it is conveyed to the remoter parts of the arms by the simple imbibition of one part from another, without any proper circulation through vessels.

443. In the lowest Mollusks, however, which bear a strong resemblance in their general habits to Zoophytes, the digestive cavity is provided with a second orifice; for, from the dilated cavity or stomach, an intestinal tube proceeds; and this has a termination distinct from the mouth, though often in its neighbourhood. The food, before entering the stomach, is submitted to a powerful triturating apparatus resembling the gizzard of birds, by which it is broken-down; and in the digestive cavity it is submitted, not merely to the action of the gastric fluid, but also to that of the bile, which is secreted in little follicles in the walls of the stomach, and which is poured into its cavity during the process of digestion,—being easily recognized by its bright yellow colour. The excrementitious matter is rejected in the form of little pellets, through the intestinal tube.

444. As we ascend the Animal scale, we find the digestive apparatus gradually increased in complexity; but its essential characters remain the same. Near the entrance to the stomach there is usually an apparatus for effecting the mechanical reduction of the food, by which its subsequent solution may be rendered more easy. This may consist of a set of teeth; either fixed in the mouth, as in Mammalia and Reptiles; or more particularly besetting the pharynx, as in Fishes; or attached to the walls of the stomach, as in Crustacea. Or it may be formed by the tongue, converted into a sort of rasp, as in the common Limpet, which thus reduces the sea-weeds that constitute its chief food. Or the same purpose may be answered by a gizzard, or first stomach, with dense muscular and tendinous walls; such as we find in the grain-eating Birds, and many Insects, as well as in certain Mollusks. But where the food is already composed of very minute particles, or is received in a liquid state (as in the case of those animals which live on the juices of others), or is easily acted-on by the gastric juice, no such preparation is requisite.

445. Before the food reaches the true digestive stomach, it is sometimes delayed in a previous cavity, in order that it may be macerated in fluid, and may be thoroughly saturated with it. This is the purpose of the *crop* of Birds, and of the first stomach or 'paunch' of Ruminant animals (§ 457). When this incorporation with fluid is not effected before the food is subjected to the triturating process, it usually takes-place concurrently with it; and in those animals which reduce their food in the mouth by the process of mastication, there is a special secretion of fluid into that cavity for this purpose; this fluid is termed Saliva, and the act by which it is incorporated with the food is termed *insalivation.* The mechanical reduction of the aliment, and its incorporation

Fig. 115.*



* A vertical and longitudinal section of the Human Stomach and Duodenum, made in such a direction as to include the two orifices of the stomach:—1. The œsophagus; upon its internal surface the plicated arrangement of the cuticular epithelium is shown; 2. the cardiac orifice of the stomach, around which the fringed border of the cuticular epithelium is seen; 3. the great end of the stomach; 4. its lesser or pyloric end; 5. the lesser curve; 6. the greater curve; 7. the dilatation at the lesser end of the stomach, which has received from Willis the name of antrum of the pylorus, and which may be regarded as the rudiment of a second stomach; 8. the rugæ of the stomach formed by the mucous membrane; 9. the pylorus; 10. the oblique portion of the duodenum; 11. the descending portion; 12. the pancreatic duct and the ductus communis choledochus, close to their termination; 13. the papilla upon which the ducts open; 14. the transverse portion of the duodenum; 15. the commencement of the jejunum; in the interior of the duodenum and jejunum, the valvulæ conniventes are seen.

with fluid, constitute, as we shall hereafter see, a very important preliminary to the true digestive process.

446. The food thus prepared is received into the *Stomach*, the form of which varies with the character of the aliment. When this is of a nature to be easily acted on by the gastric fluid, the stomach is a simple enlargement of the alimentary canal, almost in the direct line between the œsophagus and the intestinal tube; so that there is little provision for the delay of food in its cavity. But when the aliment is such as to be less readily reduced, and requires to be submitted to the action of the gastric fluid for a longer period, the stomach forms a more considerable enlargement, and is placed more out of the direct line between the œsophagus and the commencement of the intestine. The former condition obtains in the Carnivora, and particularly in those which live more upon blood than upon flesh,—such as Weasels, Stoats, &c., in which this part of the alimentary tube is almost straight; the latter condition is found among the Herbivora, and the provision for the delay of the aliment attains its greatest complexity in the Ruminant animals (§ 457). The form of the Human stomach (Fig. 115) is intermediate between that of purely carnivorous and purely herbivorous animals. As in the former, there is a direct passage from the cardiac orifice, or entrance of the œsophagus, to the pyloric orifice, or commencement of the intestine; but there is also a considerable dilatation or *cul de sac*, which is out of that line; and it appears that, during the digestive process, there is a constriction across the stomach which separates the cardiac portion from the pyloric, and causes the retention of the food in the dilated part or large extremity. The Gastric fluid is secreted in the walls of this organ, by scattered follicles which pour their products into its cavity through separate orifices (§ 469).

447. It was formerly supposed that the whole process of Digestion is performed by the agency of the gastric fluid in the Stomach; but this is now certainly known not to be the case, the process really commencing in the Mouth, and being carried on through a large part of the Intestine. It would seem as if the preparation of the food for absorption were not by any means completed in the first portion of the alimentary canal; for the Chyme, or product of Gastric digestion, is still destined to pass through a long and convoluted tube, which is sometimes extended to an extraordinary degree. The changes which are produced in the chyme by the admixture of the biliary, pancreatic, and enteric fluids, take-place in the Intestine; and the principal part of the nutritive elements of the food is taken-up by the absorbent vessels of its walls, after those changes have been accomplished. The length of the Intestinal canal bears a close relation to the character of the food. In the Carnivorous animals, whose

aliment is easily dissolved and prepared for conversion into blood, the intestine is comparatively short; thus in the Lion and other Felines it is no more than three times the length of the body; and in some of the blood-sucking Bats, it is almost straight and simple. On the other hand, in Herbivorous animals it is of enormous length; thus in the Sheep it is about twenty-eight times as long as the body. In animals whose diet is mixed, its length is intermediate between these extremes; thus in Man, the whole length of the intestinal tube is about thirty feet, or between five and six times that of the body.

448. The Intestine is of much smaller diameter along its first portion, than it is nearer its termination; and it is consequently distinguished into the *small* and the *large*. In the Small intestine, which constitutes in Man about five-sixths of the whole, the surface of the mucous membrane is greatly extended by the *valvulæ conniventes*, which are folds or duplicatures, often several lines in breadth, not entirely surrounding the intestine, but extending for about one-half or three-fourths of its circumference. These are wanting at the lower part of the ileum. The Bile, elaborated by the Liver, is transmitted from that organ by a single duct, that opens into the Intestinal tube at a short distance from its commencement (Fig. 115, 12); at the same point is delivered the Pancreatic secretion, which, as we shall hereafter see (§ 480), has a special office in the preparation of the alimentary products. The walls of the Small Intestine itself contain glandulæ which secrete a fluid that seems to take an important share in the later portion of the digestive process; this fluid is known as the 'succus entericus.' The whole surface of the mucous membrane of the Small intestine, below the entrance of the biliary ducts, is thickly covered with *villi*, or little root-like projections, in which the proper absorbent vessels originate (§ 236).—No proper valvulæ conniventes exist in the Large intestine; the only extensions of the mucous membrane being crescentic folds at the edges of the sacculi or pouch-like dilatations in its walls; and the villi are comparatively few in number, gradually disappearing towards the termination of the intestine.

449. The Mucous membrane of the alimentary canal, through its whole course, is studded with the orifices of numerous scattered Glandulæ which lie in its thickness or immediately beneath it. The simplest of these are the follicles of Lieberkühn, which are small pouches formed by an inflexion of the mucous surface, analogous to the follicles of other mucous membranes, and apparently destined for the elaboration of the protective secretion (§ 236, Fig. 35, *b*). These follicles, in the Small Intestine, are very simple in their character, and not very deep; and their apertures, which are small, are situated for the most part around the bases of the villi. In the Large Intestines they are more

prolonged, especially towards the extremity of the rectum, where they form a distinct layer, the component tubes of which are visible to the naked eye; they probably form the peculiarly thick and tenacious mucus of that part. These mucous follicles become particularly evident when the membrane is inflamed; for they then secrete an opaque whitish matter, which is absent in the healthy state, and which distinguishes their orifices.—A modified kind of these follicles, rather more complex in structure, is found abundantly in the stomach; where they are concerned in the secretion of the gastric fluid (§ 469).

450. The coats of the Intestine contain other glandulæ, of which some appear destined, like the preceding, to elaborate fluids of use in the system; whilst others may serve rather to draw-off from the blood certain products of decomposition which are to be excreted from it. To the first of these categories the glands of Brunner (§ 481) probably belong; to the second, the large solitary follicles found in the large intestines. Besides the foregoing, the walls of the intestines contain a large number of peculiar bodies, known as the 'Peyerian glands;' these, however, have no outlet into the Intestinal canal, and have been determined by late researches to belong to the Assimilating rather than to the Secreting apparatus (§ 496).

3. *Movements of the Alimentary Canal.*

451. The food which is conveyed to the Mouth is laid-hold-of by the lips, by a muscular effort which is voluntary in the adult under ordinary circumstances, but which may be performed automatically when the influence of the will is withdrawn; in the infant, as among the lower animals, the action seems purely automatic, the nipple of the mother being firmly grasped by the lips when introduced between them, even after the brain has been removed.—By the act of Mastication, which then succeeds, the food is triturated and mingled with the Salivary secretion; and is thus prepared for the further process of solution, to which it is to be subjected in the stomach. The degree of this preparation, and the form of the instruments by which it is effected, vary in different animals, according to the nature of the food. In those Carnivora whose aliment consists exclusively of flesh, very little mastication is necessary, because this substance is very readily acted-on by the gastric fluid; and we accordingly find the molar teeth raised into sharp cutting edges, and working against each other with a scissors-like action (the only one permitted by the articulation of the jaw), so as simply to divide the food. On the other hand, in those Herbivora whose food consists of tough vegetable substances, such as the leaves of grasses, or the stems and roots of other plants, we find the molar or grinding teeth pecu-

liarly adapted to its reduction; their surface being extended horizontally, and being kept continually rough by the alternation of vertical plates of different degrees of hardness; and the lower jaw being so connected with the skull that great freedom of motion is permitted. In Man we find an intermediate conformation, as regards both the teeth and the articulation of the jaw: for the molar teeth possess broad surfaces, which are covered with a continuous coat of enamel, but which are raised into rounded tubercles; and the articulation of the jaw allows it a degree of freedom which is much greater than that possessed by the Carnivora, although inferior to that which exists in many Herbivora. The whole apparatus of Mastication is so formed in Man, as to lead to the conclusion that he is destined to live on a mixed diet, composed in part of animal flesh, and in part of vegetable substances that are sufficiently soft to be reduced by the simple act of crushing, or by the slight trituration for which the molar teeth are adapted.

452. The mechanical reduction of the food by Mastication, and the incorporation of the Salivary secretion with its substance, constitute a very important step in the Digestive process. The operations to which the alimentary matter is subjected in the Stomach are of a purely Chemical nature; and this preparation is exactly of the same character as that which the Chemist finds it advantageous to make when he is operating on a substance of difficult solution. For nothing is so favourable to the action of the solvent as the previous reduction of the matter to be dissolved, and the thorough incorporation of fluid with its substance. We shall hereafter see, moreover, that the Salivary fluid itself exerts an important converting power on the Amylaceous components of the food (§ 466). Hence, the practice of eating so rapidly that Mastication and Insalivation are insufficiently performed, is extremely injurious; and the prolonged continuance of it may lay a foundation for the distressing complaint termed Dyspepsia or difficulty of digestion. Where any form of this complaint exists, too much attention cannot be paid to the efficient reduction of the food in the mouth.

453. When the aliment has been sufficiently reduced and insalivated, it is conveyed into the Pharynx by the act of *Deglutition* or swallowing. This act involves a great many distinct movements, into a minute description of which we shall not here enter; but it is desirable that its general nature should be well understood. It is one of those most purely *reflex* in its character (§ 394), and is not capable of being performed or even controlled by a voluntary effort. This statement may seem inconsistent with the fact that we swallow when we will; but it is not so in reality. The muscular movements which are concerned in deglutition, are called-forth by nerves that proceed from the Spinal

Cord, not from the Brain; these motor nerves are excited to action by the contact of solid or fluid matters with the mucous surface of the fauces, and in no other way. The impression produced by the contact is conveyed to the *Medulla Oblongata*, or portion of the spinal cord which lies within the cranium, by afferent nerves which terminate in it; and, in immediate respondence to that impression, a motor impulse is transmitted from it, which calls the muscles into the combined action necessary to produce the movement. Now this contact *also* produces a sensation, provided the Brain be sound and awake, because nervous fibres proceed from the mucous surface to the brain as well as to the spinal cord; but this sensation is not a necessary link in the chain of actions by which the movement is produced; for the act of Deglutition takes-place during profound sleep when all sensation is suspended, and it may be excited even after the brain has been removed. It *seems* to be voluntary, under ordinary circumstances, simply because it is by an act of the will that the matter to be swallowed is carried backwards into contact with the fauces; but that it is not so in reality, is shown by the fact that when this impression has once been made with sufficient force, we cannot by any effort of the will prevent the action. We have a good example of this in the following circumstance, of no very anfrequent occurrence. The tickling of the upper part of the fauces with a feather is often practised to induce vomiting; but if the end of the feather be carried too low down, it excites the act of deglutition instead; the feather is grasped by the pharynx, and drawn downwards; and if it be not held tenaciously between the fingers, it is drawn from them and carried downwards into the stomach.

454. The carrying-back of the alimentary matter, so that it reaches the fauces or upper part of the Pharynx, is principally accomplished by the tongue; when it has passed the anterior palatine arches, these contract and close over the tongue, so as to prevent the return of the food into the mouth; and at the same time the posterior palatine arches and the uvula are so drawn-together as to prevent its passage into the posterior nares. The larynx rises and is drawn forwards beneath the root of the tongue, and the epiglottis is pressed-down over the rima glottidis, so that nothing can enter the latter unless drawn towards it by an act of inspiration. When fairly within the Pharynx, the alimentary matter is seized by the Constrictors which enclose that part of the alimentary tube, and is drawn downwards by them into the Œsophagus, which is the cylindrical continuation of it. The continued action of the constrictors serves to propel the food along the œsophagus; their movement being of a reflex nature, excited by the contact of the substance contained in the tube with its lining membrane, which produces an impression that is trans-

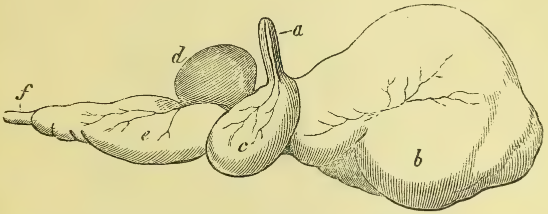
mitted to the Medulla Oblongata, and is thence reflected-back as a motor impulse to the muscles. We have here a distinct case of reflex action without sensation; for we have no consciousness of the ordinary passage of food down the œsophagus, unless it occasion pressure on the surrounding parts through its bulk, or unduly irritate the lining membrane by its high or low temperature or its acrid qualities; and yet it may be shown by experiment that the completeness of the nervous circle is requisite for the excitement of the movement, which will not take-place when it is interrupted either by division of the nerves, or by destruction or paralysis of the Medulla Oblongata.

455. The progress of the food along the Œsophagus is aided by the action of the muscular coat peculiar to it. This is composed of the non-striated fibre; and, like that of the intestinal canal further on, it is usually stimulated to contraction by the *direct contact* of the stimulus, and not either by the will, or by the reflex action of the spinal cord. The movement produced by it is of the *peristaltic* or wave-like kind; the contractions being limited to one portion of the tube, and being propagated along it from above downwards. This action continues after the division of all the nerves supplying the œsophagus; and it cannot, therefore, be dependent upon the brain or spinal cord. It may be observed to take-place in a rhythmical manner (that is, at short and tolerably regular intervals), whilst a meal is being swallowed; but as the stomach becomes full, the intervals are longer and the wave-like contractions less frequent. The degree in which the action of the œsophagus alone, without that of the surrounding muscles, is capable of propelling the food into the stomach, seems to vary in different animals. When the latter are paralysed in the Dog by section of the nerves that supply them, the food that has entered the œsophagus is still propelled into the stomach; but this is not the case in the Rabbit, the action of its œsophageal fibres not being sufficient to carry the food onwards to the stomach, though it will expel it from the divided extremity of the tube when it is cut across.—The usual peristaltic movements of the œsophagus are reversed in Vomiting; and this reversion has been observed, even after the separation of the stomach from the œsophagus, as a consequence of the injection of tartar emetic into the veins.

456. At the point where the œsophagus enters the Stomach,—the cardiac orifice of the latter,—there is a sort of sphincter, or circular muscle, which is usually closed. This opens when there is a sufficient pressure on it, made by the accumulated food propelled by the movements of the œsophogus above; and it then closes again, so as to retain the food in the stomach. The closure is due to reflex action; for when the nerves supplying it are divided, the sphincter no longer contracts, and the food regurgitates into the œsophagus. The opening of the cardia is one of the first acts which takes-place in vomiting.

457. In Ruminating animals there is a very remarkable conformation at the lower end of the œsophagus, which is destined to regulate the passage of food into the different compartments of the stomach, according as it has been submitted to the second mastication, or not. The œsophagus (Fig. 116, *a*) does not terminate at

Fig. 116.*

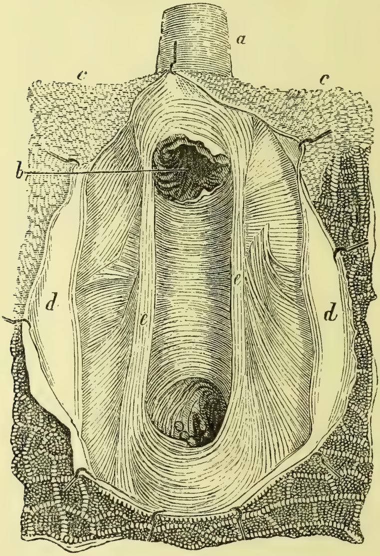


its opening into the first stomach or paunch (*b*), but it is continued onwards as a deep groove with two lips (Fig. 117): by the closure of these lips it is made to form a tube, which serves to convey the food onwards into the third stomach; but when they separate, the food is allowed to pass into either the first or the second stomach. When the food is first swallowed, it undergoes but very little mastication; it is consequently firm in its consistence, and is brought down to the termination of the œsophagus in dry bulky masses. These separate the lips of the groove or demi-canal (Fig. 117, *e*, *e*), and pass into the first and second stomachs. After they have been macerated in the fluids of these cavities, they are returned to the mouth by a reverse peristaltic action of the œsophagus; this return takes-place in a very regular manner, the food being shaped into globular pellets by compression within a sort of mould formed by the demi-canal, and these pellets being conveyed to the mouth at regular intervals, apparently by a rhythmical movement of the œsophagus. It is then subjected to a prolonged mastication within the mouth (the 'chewing of the cud'), by which it is thoroughly triturated and impregnated with saliva; after which it is again swallowed in a pulpy semi-fluid state. It now passes along the groove which forms the continuation of the œsophagus, without opening its lips; and is thus conveyed into the third stomach (Fig. 116, *d*), whence it passes to the fourth (*e*), in which alone the true digestive process takes place. Now, that the condition of the food as to bulk and solidity

* Compound Stomach of Sheep:—*a*, œsophagus; *b*, paunch; *c*, second, or honeycomb stomach; *d*, third stomach, or many-plies; *e*, fourth stomach, or reed; *f*, pylorus.

is the circumstance which determines the opening or closure of the lips of the groove, and which consequently directs its passage into the first and second stomachs, or into the third and

Fig. 117.*



fourth, appears from the experiments of Flourens; who found that when the food, the first time of being swallowed, was artificially reduced to a soft and pulpy condition, it passed for the most part along the demi-canal into the third stomach, as if it had been ruminated,—only a small portion finding its way into the first and second stomachs. How far the actions of this curious apparatus are dependent upon nervous influence,—or how far they

* Section of part of the Stomach of the Sheep, to show the demi-canal of the Œsophagus; the mucous membrane is for the most part removed, to show the arrangement of the muscular fibres. At *a* is seen the termination of the œsophageal tube, the cut edge of whose mucous membrane is shown at *b*. The lining of the first stomach is shown at *c*, *c*; and the mucous membrane of the second stomach is seen to be raised from the subjacent fibres at *d*. At *e*, *e*, the lips of the demi-canal are seen bounding the groove, at the lower end of which is the entrance to the third stomach or many-plies.

are due to the exercise of the contractility of the muscular fibre, directly excited by the contact of the substances with the lining membrane of the tubes and cavities,—has not yet been clearly ascertained.

458. The food, when introduced into the Stomach, and submitted to the solvent action of its secretions, is also subjected to a peculiar movement which is effected by the muscular walls of that organ. The purpose of this motion is obviously to keep the contents of the stomach in that state of constant agitation which is most favourable to their chemical solution; and particularly to bring every portion of the alimentary matter into contact with the walls of the stomach, so as to be subjected to the action of the fluid which is poured-forth from them during the digestive process. The movement is produced by the alternate shortening and relaxation of the various fasciculi which are disposed in almost every direction throughout the muscular wall of the stomach; and it seems to produce a kind of revolution of the contents of the stomach, sometimes in the direction of its length, and sometimes transversely. Its result is well shown in the hair-balls which are occasionally found in the stomachs of animals that have swallowed hair from time to time through licking their skins; the component hairs not being pressed into a confused mass, but being worked together in regular directions, and so interwoven that they cannot be readily separated.—As digestion proceeds, the dissolved fluid escapes, little by little, through the pyloric orifice, which closes itself firmly against the passage of solid bodies; and this motion continues until the stomach is completely emptied, when it ceases until food is again introduced. The bulk of the alimentary mass diminishes rapidly as the solvent process is near its completion; and the separation of the fluid product or chyme is aided by a peculiar action of the transverse fasciculi which surround the stomach at about four inches from its pyloric extremity. These shorten in such a manner as to produce a sort of hour-glass separation between the portions of the stomach on either side of it; and the fluid solution received by the pyloric or smaller portion is pumped-away through the pylorus, whilst the solid matter yet undissolved is retained in the larger division.

459. The degree in which these movements are dependent upon the Nervous System, or are under its control or direction, has not yet been clearly ascertained. Distinct movements may be excited in the stomach of a Rabbit, if it be distended with food, by irritating the Pneumogastrics soon after the death of the animal; these movements seem to commence from the cardiac orifice, and then to spread themselves peristaltically along the walls of the stomach; but no such movements can be excited if the stomach be empty. On the other hand, there is distinct proof that all the movements necessary to digestion may take-place after the section of those

nerves, although the first effect of the operation appears to be to suspend them completely. It is probable that the movements of the stomach are more regular and energetic in Herbivorous animals, whose food is difficult of digestion, than they are in the Carnivora, whose aliment is dissolved with comparative facility.

460. From the time that the ingested matter enters the Intestinal tube, it is propelled onwards by the peristaltic contractions of its muscular coat; which are excited by the contact of the aliment or by that of the secretions mingled with it in its passage along the canal. These last appear to have an important effect; for we find that when the bile-duct is tied, so as to prevent the bile from entering the intestine, constipation always occurs; whilst an increase of the biliary and other secretions, consequent upon the action of mercury or upon any other cause, produces an increased peristaltic movement, and a more rapid discharge of the excrementitious matter. During the passage of the alimentary matter along the small intestine, as we shall see hereafter, a large proportion of its fluid is removed by the absorbent power of the villi; and the residue is again brought, therefore, to a more solid consistence. This residue consists in part of those portions of the aliment which are not capable of being dissolved or finely divided so as to be received by the absorbents; and in part of the matters poured into the alimentary canal by the various glands that discharge their contents into it, for the purpose of being carried out of the body. The fæces, which are thus formed, are propelled through the large intestine, by the continued peristaltic action of its walls, until they arrive at the rectum.

461. That the ordinary peristaltic action of the Intestinal canal is independent of Nervous influence, seems to be indicated by the fact that it continues when the tube is completely separated from all connection with the principal nervous centres, as well as by the difficulty already adverted-to (§ 342) of exciting contractions in the muscular coat by any stimulation of the nerves of the Solar plexus. Some Physiologists, however, are of opinion that the peristaltic contractions are truly reflex, the centres of reflexion being the minute ganglia of the Sympathetic system which are scattered through the muscular coat of the Intestine itself. Although the *will* has no influence whatever on the peristaltic movement, yet the *emotions* seem to affect it: and though we are not conscious of the passage of the alimentary matter along the canal so long as it is in a state of health, yet in various diseased conditions its passage may give rise to sensations of the most painful nature. These two facts indicate that the Intestinal canal is brought into connection with the Cerebro-Spinal system through the nerves of the Solar plexus; and this inference is confirmed by certain experimental facts hereafter to be stated (CHAP. XIII., Sect. 8).

462. For the occasional discharge of the fæces from the Rectum, and for the retention of them at other times, we find the outlet or anal orifice provided with an additional muscular apparatus, which is connected with the Spinal system of nerves. The act of Defecation is due to the pressure upon the contents of the rectum, which is occasioned by the combined contraction of the diaphragm and the abdominal muscles; whilst, on the other hand, the retention of the fæces is due to the contractile power of the Sphincter muscle which surrounds the anus. The action of the sphincter ani, like that of the sphincter of the cardia, is a reflex one; being dependent upon the connection of the muscle, by excitor and motor nerves, with the Spinal cord. If the lower portion of the Cord be destroyed, or if the nerves be divided, the sphincter loses its contractile power and becomes flaccid. When in proper action, however, its power is sufficient to prevent the escape of the contents of the rectum; until the expulsive force becomes very strong, in consequence either of the quantity of fæces which have accumulated, or the acridity of their character. In either case, the impression made upon the mucous membrane of the rectum is conveyed to the Spinal Cord; and, by a reflex motor impulse, the muscles of defecation are thrown into combined action, the resistance of the sphincter is overcome, and the fæces are expelled. An unduly irritable state of the mucous membrane, or a disordered state of the excrementitious matter (resulting from the irritating character of the substances swallowed, from the acrid character of the secretions poured into the canal, or from an unusual change in the aliment during the digestive process), may occasion unduly-frequent calls upon the muscles of defecation, which the sphincter is unable to resist. On the other hand, if the progress of the fæces be delayed in the large intestine by deficient peristaltic movement, they accumulate higher up, and the act of defecation is not excited.

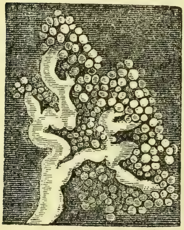
463. Although the Sphincter ani on the one hand, and the muscles of Defecation on the other, are called into action by the reflex power of the Spinal Cord, and are so far involuntary in their operation, yet they are also in some degree subject (in Man at least) to the influence of the Will. The resistance of the sphincter may be increased by a voluntary effort, when it is desired to retain the fæces in opposition to the power of the expulsors; and it is only when the latter operate with excessive force, that they can overcome it. On the other hand, the expulsors may be called into action, or may be aided, by the will, when the stimulus to their movement received through the spinal cord would not otherwise be strong enough; and the fæces may thus be evacuated by a voluntary effort, at a time when they would not else be discharged.

4. *Of the Secretions poured into the Alimentary Canal, and of Changes which they effect in its contents.*

464. The whole Mucous Membrane of the Alimentary canal from the mouth to the anus, is covered during health with that peculiar viscid secretion termed *mucus*, of which the characters have been already described (§ 238). This is formed, partly, on the free surface of the membrane itself, but chiefly in the numerous follicles or depressions by which that surface is increased (§ 449) ; and it appears destined for the protection of the delicate highly vascular membrane from undue irritation by the contact of the substances which are passing through the alimentary tube. When these are unusually acrid, the secretion of mucus is augmented in quantity and is increased in viscidity, so as to form an effective sheath to the membrane which would otherwise suffer severely. If this secretion be deficient, the membrane is irritated by the contact of any but the blandest substances; and the class of remedies termed *demulcents* are useful in coating and protecting it.

465. During the mastication of the food in the mouth, the *Salivary* secretion is poured-in for the purpose of being mingled with it, and of rendering the acts of mastication and deglutition more easy. This secretion is formed by three pairs of glands,—the Parotid, the Sub-lingual, and the Sub-maxillary; these are composed of minute follicles whose diameter is about 1-1000th of an inch, connected together by branches of their duct, upon which they are set like grapes upon their stalk (Fig. 118), surrounded by a plexus of blood-vessels (Fig. 44), and bound-together by areolar tissue. Within the follicles are the true secreting cells (§ 243), by whose growth and development the material of the secretion is separated from the blood. These salivary cells are often to be recognized in the saliva; they must not, however, be confounded with the epithelium-cells of the mucous membrane of the mouth, which are much larger. The fluid obtained from the mouth is not pure saliva; for the mucus of the mouth itself is mingled with the secretion from the salivary glands. If the proportion of the former be considerable, it gives to the fluid of the mouth a slightly acid reaction; whilst, if the latter be predominant (which it is

Fig. 118.*



* Lobule of Parotid Gland of new-born Infant, filled with mercury; magnified 50 diameters.

directly before, and during, the act of eating), the fluid of the mouth has an alkaline reaction. It may be sometimes observed that the saliva of the mouth will strike a blue colour with reddened litmus-paper, whilst it turns blue litmus-paper red; thus showing the presence both of an acid and an alkali in a state of imperfect neutralization.

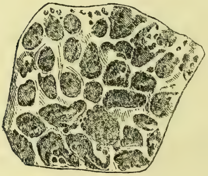
466. The solid matter of the Salivary secretion, taken as a whole, is from 0·5 to 0·7 per cent.; and is composed in part of animal principles, and in part of saline substances. The animal matter consists of mucus with a peculiar substance termed *ptyalin* or salivary matter, which is soluble in water and insoluble in alcohol, and which is specially distinguished by its remarkable power of transforming starch first into Dextrin, and then into Grape-Sugar; one part of Ptyalin dissolved into water effecting this conversion in 2000 parts of Starch, and traces of Sugar being found in Starch-paste which had been kept in the mouth for no more than 30 seconds. Its chemical nature has not yet been precisely determined, but it seems to be a derivative of Albumen; and it has been found that other Albuminous compounds in a state of incipient decomposition can exert a converting power of the same kind, though less in degree. The saline constituents of the Saliva are nearly identical with those of the blood; the chlorides of sodium and potassium form about half; and the remainder consists chiefly of the tribasic phosphate of soda, to which the alkaline reaction of the fluid is due, with the phosphates of lime, magnesia, and iron. It is of the earthy phosphates that the *tartar* which collects about the teeth is chiefly composed, the particles of these being held together by about 20 per cent. of animal matter; and the composition of the concretions which occasionally obstruct the salivary ducts, is nearly the same.—It appears, however, from recent observations, that the products secreted by the several Salivary glands are by no means identical. The fluid of the Parotid glands is clear, limpid, and thin as water, and contains but a small proportion of solid matter; that of the Sublingual, on the other hand, is thick and viscid, resembling ordinary simple syrup in colour and consistence, and containing a far larger proportion of solid matter; whilst that of the Submaxillary is intermediate in its characters between these two. The first liquid is secreted most abundantly during mastication, and seems especially destined to saturate the food; the second is poured-forth most copiously just as the masticated bolus is being swallowed, and seems destined to facilitate the act of deglutition. What is the relative transforming power of these two liquids, has not been conclusively ascertained; but it seems beyond doubt that the activity of the proper Salivary secretion is greatly augmented by admixture with the Mucus of the mouth; the total effect of

Buccal digestion consisting in the Saccharine transformation of part of the Amylaceous constituents of the food.

467. The quantity of Saliva formed during the twenty-four hours is probably between one and two pounds; on this point, however, it is impossible to speak with certainty. The secretion is by no means constantly flowing; indeed it is almost entirely suspended when the masticator muscles and tongue are at perfect rest, unless it be excited by any mental cause; and hence it is that the mouth becomes dry during sleep, if it be not kept closed. The flow of Saliva takes-place just when it is most wanted; that is, when food has been taken into the mouth, and when the operation of mastication is going-on. But it will also take-place, especially in a hungry person, at the sight, or even at the idea, of savoury food; as is implied by the common expression of the 'mouth watering' for such an object. The influence thus exercised over it seems to be conveyed to the Salivary Glands through the nervous circle formed through the gustatory branch of the Fifth and the Glosso-pharyngeal as 'afferent' nerves, and the temporo-auricular branch of the Fifth and the chorda tympani of the Facial as 'efferent' nerves; another circle being formed by the sympathetic branches of the Submaxillary ganglion. When the secreting action of these glands is actively going on, the arterial twigs that supply them enlarge, the rapidity of the blood-current increases, and the veins pulsate and bring back scarlet blood.

468. Having been conveyed into the Stomach, the food is submitted to the action of the Gastric Juice, which is secreted in the walls of that organ. This fluid is not present in the empty stomach; its secretion being excited by the presence of food, or by the irritation of the walls of the organ by some solid body. In the intervals between the digestive process, the Mucous membrane is of a light pink hue; but it becomes more turgid with blood when the presence of food calls for the activity of its secreting processes. It is of a soft and velvet-like appearance; and it is constantly covered with a very thin transparent viscid Mucus, which has neither acid nor alkaline reaction. Its surface generally presents under the Microscope a sort of honey-combed appearance (Fig. 119), produced by a multitude of small depressions or pits, into the bottom of which the secreting follicles open; their diameter varies from about 1-100th to 1-250th of an inch, being greatest near the pylorus; and the number of secreting follicles

Fig. 119.*

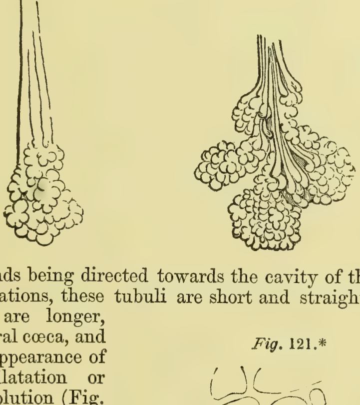


* Portion of the surface of the Mucous Membrane of the Stomach, showing the pits into which the Gastric follicles open.

opening into each is usually from three to five. These pits are separated from one another by membranous partitions of variable depth, and sometimes, especially near the pylorus, by pointed vascular processes that seem like rudimentary villi, save that they contain no lacteals. The number of the secreting follicles, of which some secrete Gastric juice and others Mucus, has been estimated as not less in the Human Stomach than *five millions.*

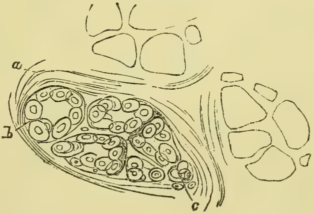
469. If the Mucous Membrane of the stomach be divided by a section perpendicular to its walls, it is seen to be almost made-up of such tubular follicles, which are closely applied to each other, their blind extremities resting upon the submucous tissue, and

A *Fig.* 120.* B



their open ends being directed towards the cavity of the stomach. In some situations, these tubuli are short and straight; in other parts they are longer, give off several cœca, and present an appearance of irregular dilatation or partial convolution (Fig. 120, A). This is their usual character, especially in the cardiac portion of the stomach; but near the pyloric orifice some of them have a much more complex structure (Fig. 120, B). These tubular follicles are arranged in bundles or groups (Fig. 121, *b*), and are sur-

Fig. 121.*



* Glandulæ from the coats of the Stomach, magnified 45 diam.;—A, from the middle of the stomach; B, from the neighbourhood of the pylorus.

† Transverse section of cluster of Gastric glandulæ;—*a*, connective tissue bounding clusters; *b*, one of the tubular follicles; *c*, contained cells.

rounded and bound together by Connective tissue (*a*); and this also serves to convey vessels from the submucous tissue, which ramify among the follicles, and supply the materials for their secretion. The number of tubuli in each group is by no means constant. It appears that the mucus-secreting follicles are lined throughout by ordinary cylinder-epithelium, as are also the tubular portions of the gastric glands; whilst the follicles that secrete the gastric fluid are distinguished by the blocking-up of the greater part of the cavity of their branching tubular cœca by large globular cells (*c*). When the stomach is empty, the cylinder-epithelium which lines the principal gastric tubuli completely blocks up their orifices, so that during fasting these appear as slightly prominent papillæ; but when the secretion of gastric fluid commences, this epithelium is cast forth by pressure from beneath, the globular cells of the follicles being then discharged, and giving up their contents either by bursting or dissolving away.

470. The chemical composition of the Gastric juice has been a subject of much discussion, and can scarcely yet be regarded as precisely determined: it seems to vary, indeed, both according to the state of the system, and the kind of animal from which the fluid is obtained. In all cases, however, this fluid appears to contain a free acid, together with a peculiar organic compound, *Pepsin*, which seems like albumen in a state of change. It is in regard to the nature of the free acid that Chemists are most at issue. Hydrochloric, phosphoric, acetic, lactic, and butyric acids, have each been detected in the gastric fluid; but there are great difficulties in the way of determining which of these acids are free, and which are in combination. Thus, although it is very easy to obtain free hydrochloric acid by distillation of the gastric fluid, yet this is by no means an adequate proof of the previous presence of the acid in a free state; for it has been found that free lactic acid will decompose chloride of sodium at an elevated temperature, forming (with water) lactate of soda and hydrochloric acid; so that the lactic may be the free acid of the gastric fluid, the hydrochloric having been formed during the distillation, at the expense of the chloride of sodium, which is a constituent of the gastric fluid. It has been further determined that hydrochloric and lactic acids both possess a remarkable solvent power for Albuminous matters, when assisted by pepsin; so that it is probable that they may replace one another. The proportion of Pepsin in the Gastric juice of Man appears to be about 3 parts in 1000. Its properties have been principally studied in that form of it obtained from the mucous membrane of the stomach of the Pig, which bears a close resemblance to that of Man. When this membrane is digested in a large quantity of water at from 85° to 90°, it is purified from the various soluble substances it may contain, but little pepsin being taken-up with them. By

continuing the digestion in *cold* water, the pepsin is then extracted nearly pure. When this solution is evaporated to dryness, there remains a brown, yellowish, viscid mass, having the appearance of an extract and the odour of glue. A similar substance may be obtained by adding strong alcohol to a fresh solution of pepsin; for the latter is then precipitated in white flocks, which may be collected on a filter and produce a grey compact mass when dried. There is reason to think that these two factors of the Gastric fluid are separately secreted; the Pepsin being elaborated in the glandular follicles, and the Acid being poured forth on the most superficial cellular layers of the Mucous Membrane.

471. Pepsin enters into chemical combination with many acids, forming compounds which still redden litmus-paper; and this appears to be its condition in the gastric juice. The muriate and acetate of pepsin possess a very remarkable solvent power for albuminous substances. A liquid which contains only 17 ten-thousandths of acetate of pepsin, and 6 drops of hydrochloric acid per ounce, possesses solvent power enough to dissolve a thin slice of coagulated albumen in the course of six or eight hours' digestion. With 12 drops of hydrochloric acid per ounce, the same quantity of white-of-egg is dissolved in two hours. A liquid which contains only half a grain of acetate of pepsin, and to which hydrochloric acid and white-of-egg are alternately added, so long as the latter is dissolved, is capable of taking up 210 grains of coagulated white-of-egg, at a temperature between 95° and 104°. The same acid with pepsin dissolves blood, fibrin, meat, and cheese; whilst the acid without the pepsin requires a very long time to do so at ordinary temperatures. Very dilute hydrochloric acid, however, at the boiling point, dissolves these albuminous substances; and the solution has the same character as that which is made by the agency of pepsin. The horny tissnes, such as the epidermis, horn, hair, &c., and the yellow fibrous tissue, are not affected by the acid solution of pepsin.—It appears from these experiments, that the acid is the real solvent; and that the action of the pepsin is limited to *disposing* the albuminous matter for solution, producing in it a change analogous to that which may be effected by heat. Hence it may be considered, like ptyalin, as a sort of *ferment;* its office being to produce a tendency to change in the substances on which it acts, without itself entering into new combinations with any of their elements.

472. These experiments appear to afford an explanation of the properties of the Gastric fluid, as ascertained by direct experiment upon it. When drawn direct from the Human stomach, it is found to possess the power of dissolving various kinds of alimentary substances, whilst these are submitted to its action at a constant temperature of 100° (which is about that of the stomach), and are frequently agitated. The solution appears to be in all respects as

perfect as that which naturally takes-place in the stomach; but a longer time is required to make it. This is easily accounted-for by the difference of the conditions; for no ordinary agitation can produce the same effect with the curious movements of the stomach (§ 458); fresh gastric fluid is poured-out, as it is wanted, during the natural process of digestion; and the continued removal of the matter which has been already dissolved, by its exit through the pylorus, is of course favourable to the action of the solvent upon the remainder. The quantity of food which a given amount of gastric fluid can dissolve, is limited; precisely as in the case of the acidulous solution of pepsin. The marked influence of temperature upon its action is shown by the fact, that fresh gastric fluid has scarcely any influence on the matter submitted to it, when the bottle is exposed to cold air, instead of being kept at a temperature of 100°. Hence the use of a large quantity of cold water at meal-times, or of ice afterwards, must retard the digestive process.—The gastric fluid of Carnivorous animals has a strongly acid reaction, and is peculiarly efficacious in dissolving Animal Albumen; that of Herbivora is weakly acid, and is far more efficacious in dissolving Vegetable Albumen or Gluten. The gastric fluid of Man seems most to resemble that of the Herbivora.

473. The pulpy substance which is the product of the reducing action of the gastric juice, is termed *Chyme*. Its consistence will of course vary, in some degree, with the relative quantity of solids and liquids ingested. In general it is greyish, semifluid, and homogeneous; and possesses a slightly acid taste, but is otherwise insipid. When the food has been of a rich oily character, the Chyme possesses a creamy aspect; but when the food has chiefly consisted of farinaceous matter, it has rather the appearance of gruel. The state in which the various alimentary principles exist in it, has not yet been accurately determined; the following, however, may be near the truth.—The Albuminoid compounds, whether derived from Animal or Vegetable food, are all reduced to one common form, distinguished by its peculiar properties from any of the substances at the expense of which it has been elaborated. This *Albuminose** is not coagulable by heat or by nitric acid; and it has a much greater power of transudation through animal membranes than that possessed by Albumen (§§ 491, 492). As Albuminose is not found in the chyle or blood, except immediately after digestion, it would seem as if this conversion is temporary only, for the purpose of promoting the absorption of Albuminous substances.—Gelatin will be dissolved or not, according

* The substance here termed *Albuminose*, after Mialhe and Dalton, seems to be the same with the *Peptone* of German chemists. It is remarkable that its presence interferes with the action of Iodine upon Starch, and with that of Trömmer's test upon Sugar.

to its previous condition; if it exist in a tissue from which it cannot readily be extracted, it will pass-forth almost unchanged; but when ingested in a state of solution, it remains so; and if it have been previously prepared for solution by boiling, its solution is completed in the stomach. Its condition, however, is altered in the process; for its power of gelatinizing is either lost or diminished, while its power of transudation is increased; and it cannot be detected as Gelatin in either the Blood or the Chyle.—The Gummy matters of Vegetables are dissolved, when they exist in a soluble form; as in the case of pure gum, pectin, and dextrin or starch-gum. It does not appear, however, that any further conversion of Starch is effected by the gastric fluid; for if no saliva be admitted into the stomach, no sugar is generated there by the metamorphosis of the starch which it may contain. But the continued introduction of the saliva ordinarily occasions the continuance of the process, although the presence of the free acid of the gastric fluid in some degree interferes with it; and it is not until this has been neutralized by the admixture of the biliary and pancreatic secretions, that the metamorphosis of the starch is actively renewed. Any sugar that may have been taken-in as such, or that may have been produced from starch by the converting power of the saliva, is reduced to the state of complete solution.—Oily matters do not appear to be in any way acted upon, otherwise than by being set-free by the solution of the envelopes which may have contained them (*e. g.* fat-cells), and by being dispersed through the mass; their state of division, however, does not seem to be yet fine enough to allow of their absorption.—Most other substances, as resins, woody fibre, horny matter, yellow fibrous tissue, &c., pass unchanged from the stomach, and undergo no subsequent alteration in the intestinal canal; so that they are discharged among the fæces as completely useless.—On the whole it may be said that the essential change effected by *Gastric* digestion is limited to the *azotized* constituents of the food.

474. We have now to notice the conditions under which the Gastric fluid is secreted; the knowledge of which is of great practical importance. We have seen that it is not poured-forth except when food is introduced into the stomach, or when its walls are irritated in some other mode; and there is reason to believe that the liberation of its acid constituent at least is immediately due to the stimulus applied to the mucous membrane. The quantity of the fluid then poured into the stomach, however, is not regulated by the amount of food ingested, so much as by the wants of the system; and as only a definite quantity of food can be acted-on by a given amount of gastric juice, any superfluity remains undissolved for some time,—either continuing in the stomach until a fresh supply of the solvent is secreted, or passing

into the intestinal canal in a crude state, and becoming a source of irritation, pain, and disease. The ingestion of a small quantity of salt, pepper, mustard, or other irritating substances, appears to produce a gently-stimulating effect upon the mucous membrane, and by causing an increased afflux of blood, to augment the quantity of the gastric fluid poured-forth. Any excess of these or other irritants, however, produces a disordered condition of the mucous membrane, which is very unfavourable to the digestive process. It becomes red and dry, with an insufficient secretion of mucus; the epithelial lining is abraded, so that the mucous coat is left entirely bare; and irregular circumscribed patches of a deeper hue, sometimes with small aphthous crusts, present themselves here and there on the walls of the stomach. Similar results follow excess in eating. When these changes are inconsiderable, the appetite is not much impaired, the tongue does not indicate disorder, and the digestive process may be performed; but if they proceed further, dryness of the mouth, thirst, accelerated pulse, foulness of the tongue, and other symptoms of febrile irritation manifest themselves; and no gastric secretion can then be excited by the stimulus of food. Similar results may follow the excitement of the emotions; and those of a depressing nature seem especially to produce a pale flaccid condition of the mucous membrane, which is equally unfavourable to the due secretion of gastric fluid.—The Pneumogastric nerve seems most probably to be the channel through which mental emotions and other states of the general system affect this process; since experiment shows that section of it (on both sides) usually has the effect of suspending the secretion for a time. If, however, the life of the animal be sustained long enough, there is adequate evidence that the secretion may be renewed; so that it cannot be *dependent*, as some have maintained that it is, upon Nervous agency. It does not appear that the nerves of the Sympathetic system have any considerable influence over this secretion.

475. The total quantity of Gastric fluid ordinarily secreted by a healthy adult, in the course of every twenty-four hours, is estimated by Bidder and Schmidt at as much as from 14 to 17 *pounds*, containing about 6 *ounces* of solid matter; other estimates, however, place it at *double*, and others again at not more than *one-fourth*, that amount. From the experiments of Dr. Dalton upon Dogs, he is led to conclude that for the solution of *one pound* of meat, no less than *thirteen pints* of gastric juice are required; and, as he justly remarks, "this quantity, or any approximation to it, would be altogether incredible, if we did not recollect that the Gastric juice, as soon as it has dissolved its quota of food, is immediately reabsorbed, and again enters the circulation, together with the alimentary substances which it holds in solution. There is accordingly, during digestion, a constant circulation of the

digestive fluids from the blood-vessels to the alimentary canal, and from the alimentary canal back again to the blood-vessels." That the quantity secreted for each act of Digestion is ordinarily proportioned to the wants of the system,—that the introduction of any superfluous aliment into the stomach is not only useless but injurious, as giving rise to irritation,—that incipient disorder of the Stomach may occur, rendering it less fit than usual for the discharge of its important duties, without manifesting itself by the condition of the tongue,—that when the tongue *does* indicate disorder of the stomach, such disorder is usually considerable,—and that every particle of food ingested, in such states as prevent the secretion of gastric fluid, is a source of fresh irritation,—are truths which cannot be too constantly kept in mind. There can be no doubt that the habit of taking more food than the system requires, is a very prevalent one; and that it is persevered-in, because no evil result *seems* to follow. But when it is borne in mind that this habit must keep the Stomach in a state of continual irritation, however slight, it can scarcely be doubted that the foundation is thus laid for future disorder of a more serious kind. Two circumstances especially tend to maintain this practice in adults, independently of the mere disposition to gratify the palate. One is the habit of eating the same amount of food as during the period of growth, when more was required by the system. The other is the custom of eating too fast; and this is injurious,—both by preventing sufficient mastication, and thus throwing on the stomach more than its proper duty,—and also by causing an over-supply of food to be ingested, before there is time for the feeling of satisfaction to replace that of hunger (§ 486).

476. Of the Albuminous, Saccharine, and other matters dissolved in the Chyme, there is reason to believe that part are absorbed through the blood-vessels so copiously distributed on the walls of the stomach (§ 492); the remainder, with the undissolved matters, passing into the duodenum, where the chyme is mingled with the *biliary* and *pancreatic* secretions.—The secretion of *Bile* is evidently a process of the highest importance in the economy; as we may judge alike from the size of the Liver and the supply of blood it receives, and from the rapidly-fatal effects of its suspension. That a part of it is purely excrementitious, and is poured into the intestinal tube for the purpose of being carried out of the body, can scarcely be questioned; but there is strong evidence that a part of it is destined to be absorbed again, after performing some action of importance upon the contents of the alimentary canal.—In all but the very lowest animals, we find traces of a Bile-secreting apparatus; and this is almost constantly situated in the immediate neighbourhood of the stomach. In many cases, the secretion is poured directly into the cavity of that organ; but in most, it is conveyed (as in Man) into the intestinal

tube near its commencement. Hence it seems clear, from the disposition of the biliary apparatus, that it has a purpose to serve in connection with the digestive function, and is not destined solely for the elaboration of a product which is to be cast-out of the body; since, if the latter were the case, that product would be carried-out immediately, like the urinary excretion, and would not be discharged into the alimentary canal high up.—This conclusion is confirmed by experiment; for it has been shown that if the Bile-duct be divided, and be made to discharge its contents externally through a fistulous orifice in the walls of the abdomen, instead of into the intestinal canal, those animals which survive the immediate effects of the operation, exhibit indications of the imperfect performance of the digestive process. At first they eat much, but their food does not seem to impart to them an adequate amount of nutrition; afterwards they lose their appetite, become thin, and usually die after an interval of some weeks or months passed in this state. If, however, they be allowed to lick the orifice, so as to receive the fluid discharged from it into their stomachs, these injurious results do not follow.—Observation of disease in the Human subject leads to similar conclusions; for when the biliary secretion is deficient, or its flow into the intestine is obstructed, the digestive processes are evidently disordered, the peristaltic action of the bowels is not duly performed, the fæces are white and clayey, and there is an obvious deficiency in the supply of nutriment prepared for the absorbent vessels.

477. On the other hand, that one great object of the secretion is to withdraw from the Blood certain products of the decomposition of the tissues, which would otherwise accumulate in it, and would be deleterious to its character, is shown by evidence yet more decisive. We find that the action of the Liver is *constant*, and not occasional, like that of the Salivary and Gastric glands; and that, if anything interfere with the secreting process, and thereby cause the accumulation of the elements of the bile in the blood, the effects of their presence are immediately manifested in the disorder of other functions, especially those of the nervous system (§ 399); and the continued suspension of the function leads to a fatal result, unless the elements of the bile are drawn off (as sometimes happens) by the Urinary organs. When the secreting action of the Liver has once been performed, however, an obstruction to the discharge of the bile into the intestine does not seem to be so immediately injurious. The fluid accumulates, and distends the bile-ducts and the gall-bladder; and when they are completely filled, part of it is re-absorbed into the blood, apparently in a changed condition, since it does not *then* produce the same injurious effects as result from the accumulation of its materials previously to the action of the Liver upon them. The colouring-matter seems to be very readily taken-back into the

circulating system; and is deposited by it in almost every tissue of the body.

478. Although the secreting action of the Liver is constant, yet the discharge of Bile into the intestine is certainly favoured by the presence of chyme in the latter. The purpose of the Gall-bladder is obviously to permit the accumulation of bile, when it is not wanted in the intestine; and we find it most constantly present in those tribes of animals which live upon animal food, and which therefore take their aliment at intervals; whilst it is more frequently absent in those herbivorous animals in which the digestive process is constantly going-on. The middle coat of the Bile-ducts is clearly muscular, and has a peristaltic action like that of the intestinal canal; this action may be excited by galvanism, or by irritation of the branches of the Sympathetic nerve with which it is supplied. The mucous coat of the Ductus Choledochus is disposed in valvular folds, in such a manner as to prevent the reflux of the bile or of the contents of the intestine; and a still further security is afforded by the valvular covering to the orifice of the duct, which is furnished by the mucous covering of the intestine itself. The flow of bile into the intestine, when its presence is needed there, is commonly imputed to the pressure of the distended Duodenum against the gall-bladder; but it is probable that the contractility of the muscular coat of the duct itself, which may be excited either through the sympathetic nerve, or by irritation at the orifice of the duct (as in the case of the Salivary glands), is the real cause of the discharge of the fluid. It is an interesting fact, which proves how much the passage of the Bile into the Intestine is dependent upon the presence of aliment in the latter, that the gall-bladder is almost invariably found turgid in persons who have died of starvation; the secretion having accumulated through the want of demand for it, although there was no obstacle to its exit.—The quantity of bile daily poured into the intestinal canal, is estimated by Bidder and Schmidt at about 56 ounces, containing about $2\frac{1}{2}$ oz. of solid matter.

479. The composition of the Bile, and the structure of the organ which elaborates it, will be more appropriately considered hereafter when the Secreting apparatus generally is being described (CHAP. X.). At present, we have to inquire what is the precise effect of its admixture with the products of digestion, and what is the purpose which this admixture serves.—In the first place, it may be stated that biliary matter is essentially a soap, formed by the union of a fatty acid with a soda-base; and that it serves the purpose of partially neutralizing the acidity of the chyme, which is derived from the gastric juice. Further, the bile shares with the pancreatic fluid in that emulsifying power by which the fatty matters of the food are reduced to a state of such fine division as to be rendered capable of being absorbed; and its alkalinity

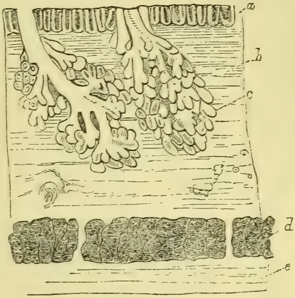
appears specially to favour the passage of the oleaginous particles into the Lacteals. No substance corresponding to the peculiar ferments of the saliva, gastric juice, and pancreatic secretion, have been detected in bile; and it does not seem to exert any converting power upon either of the constituents of the Chyme. Indeed its presence appears rather to check those putrefactive changes in the contents of the Alimentary canal, which might proceed too rapidly under the unrestrained action of those ferments, as often occurs when this secretion is deficient. The presence of Bile further appears useful in exciting the peristaltic contraction of the walls of the Intestinal tube; inspissated ox-gall being found to have a decided action as a purgative.

480. The *Pancreatic* secretion has a chemical constitution very analogous to that of Saliva; but the peculiar organic compound which it contains, has been found by M. Bernard to possess a special power of emulsifying fatty matter when mingled with it; and there is strong reason to believe that the chief purpose of this secretion is to effect such a change in the condition of the oleaginous constituents of the chyme, as may prepare them for absorption. But, further, the partial neutralization of the acid of the gastric fluid now allows the metamorphosis of starch to be recommenced; and as the production of sugar continues to take place during the passage of the chymous mass along the Small Intestines, in animals whose food is partly or completely vegetable, the Pancreatic fluid, which has been experimentally ascertained to possess the power, is probably the chief agent by which that conversion is effected. It is obviously advantageous that the Starch of the food should be again subjected to this agency after the process of Gastric digestion, in which the envelopes of the starch-grains will be softened, if not dissolved, and the grains themselves will have been rendered more ready for conversion by the influence of the combined warmth and moisture of the stomach. It appears from experiment that the Pancreatic fluid has also some power of converting Albuminous substances into Albuminose, especially if it be weakly acidified.

481. Besides the foregoing secretions, there is poured into the upper part of the intestinal canal a fluid secreted in its own walls, which has received the designation of *Succus Entericus*. It seems not improbable that the secretion of this fluid may be the function of the Glands of Brunner; which are small clusters of follicles (Fig. 122), not unlike those of which the salivary glands are composed, lying between the mucous and muscular coats of the duodenum and the commencement of the jejunum. The 'intestinal juice' appears, from the researches of Bidder and Schmidt, to be a colourless viscid liquid, invariably alkaline in its reaction, and containing from 3 to $3\frac{1}{2}$ per cent. of solid matter. The total amount daily secreted by Man is estimated by these experimenters at about 7 oz. Its properties, according to them,

are extremely remarkable; for it exerts a solvent action on albuminous bodies hardly inferior to that of gastric juice, and a power of converting starch into sugar which is scarcely less than that of saliva or the pancreatic fluid.

Fig. 122.*



482. The fluid of the Small Intestines, compounded of the Salivary, Gastric, Intestinal, Biliary, and Pancreatic secretions, appears to possess the very peculiar power of dissolving, or of reducing to an absorbable condition, alimentary substances of every class. The process goes-on during the passage of the contents of the alimentary canal along the Small Intestine; and the nutritious matter, thus progressively prepared for absorption, is gradually withdrawn by the absorbents and blood-vessels of the villi (§§ 492, 494), leaving only the excrementitious residue, which, in the Large Intestine, gradually acquires the consistence of Fæces. It has been ascertained by microscopic examination of fæcal matter, that it contains the cell-walls and other similar constituents both of Vegetable and Animal food; the cell-contents having been removed by the digestive process. Even Muscular fibre is thus traceable to such an extent as to justify the belief that the portion of meat which undergoes digestion is not its completely-organized substance. The peculiar odour of Fæces appears to be derived, not from putrefactive changes in the undigested residue of the food, but from special secretions elaborated in the walls of the Large Intestine. It has been shown by Prof. Liebig that this odour may be artificially imitated by the action of caustic potass at a high temperature upon Albuminous substances; and it is probable, therefore, that the proper fæcal matter is the product of a retrograde metamorphosis of azotized compounds which have served their purpose in the economy and are only fit to be cast forth from it.—The quantity of Fæcal matter passed by an adult seems to vary from 2 oz. to 10 oz. daily; of this nearly three-fourths consist of Water; and of the fourth part of solid matter, from 23 to 31·5 per cent. (the proportion being the

* Vertical section of Mucous Membrane of Jejunum, showing Brunner's Glands; *a*, follicles of Lieberkühn; *b*, cellular coat of intestine; *c*, Brunner's glands; *d*, annular fibres of muscular coat; *e*, longitudinal fibres of muscular coat.

highest when an abundant meat-diet has been consumed) consists of Earthy and Alkaline salts, especially the Phosphates of Lime and Magnesia. The quantity of Nitrogen removed by the Fæces is very small; their components chiefly consisting of C, H, O. Although the principal constituents of Bile can be easily recognized in the upper part of the Small Intestine, they show themselves in less and less amount the further down they are looked for, save when (as happens in purgation) the contents of the canal are forced onwards with unusual rapidity; and it appears that little save its Colouring matter ordinarily finds its way into the fæces; the rest having been re-absorbed during the passage of the Alimentary mass through the Intestinal tube.—The act of Defecation, by which the excrementitious matter is discharged, has been already noticed (§ 462); the Absorption of nutritive matter will be treated-of in the succeeding Chapter.

5. *Of Hunger, Satiety, and Thirst.*

483. The want of solid aliment is indicated by the sensation of Hunger; and the deficiency of fluid by that of Thirst. On the other hand, the presence of a sufficiency of food or liquid in the stomach is indicated by the sense of Satiety. These sensations are intended as our guides in regard to the amount of aliment we take-in. What is the real seat of these sensations, and on what conditions do they depend?—The sense of Hunger is referred to the Stomach, and seems *immediately* to depend upon a certain condition of that organ; but what that condition is has not been precisely ascertained. It is not produced by mere emptiness of the stomach as some have supposed; for, if the previous meal have been sufficient, the food passes entirely from the cavity of the stomach before a renewal of the sensation is felt. It cannot be due to the action of the gastric fluid upon the coats of the stomach themselves; because this fluid is not poured into the stomach, except when the production of it is stimulated by the irritation of the secreting follicles. It has been attributed to distension of the gastric follicles by the secreted fluid; but there is no evidence that the fluid is secreted before it is wanted; and, moreover, as it is well known that mental emotion can dissipate in a moment the keenest appetite, it is difficult to imagine how this can occasion the emptying of the follicles. Perhaps the most satisfactory view is that which attributes the sense of hunger to a determination of blood to the stomach, preparing it for the secretion of gastric fluid; since this is quite adequate to account for the impression made upon the nerves; and it accords with what has just been stated of the influence of mental emotions, since we know that these have a powerful effect upon the circulation of blood in the minute vessels (§ 603).

484. Although the sense of Hunger is immediately dependent, in great part at least, upon the condition of the stomach, yet it is also indicative of the condition of the General System; being extremely strong when the body has undergone an unusual waste without a due supply of food, even though the stomach be in a state of distension; whilst it is not experienced, if, through the general inactivity of the system, the last supply has not been exhausted, even though the stomach has been long empty. It is well known that when food is deficient, the attempt to allay the pangs of hunger by filling the stomach with non-nutritious substances is only temporarily successful; the feeling soon returning with increased violence, though it has received a temporary check. The reason for this is, obviously, that the general system has received no satisfaction, although the stomach has been caused to secrete gastric fluid by the contact of solid matter with its walls; so that although the state on which hunger immediately depends has been for a time relieved, this state is soon renewed, unless the solid matter introduced into the stomach be of an alimentary character, and be dissolved and carried into the system.

485. When the food is nutritious in its character, but of small bulk, experience has shown the advantage of mixing it with non-nutritious substances, in order to give it bulk and solidity; for if this be not done, it does not exert its due stimulating influence upon the stomach; the gastric juice is not poured-forth in proper quantity; and the result is, that neither is the sense of hunger relieved, nor are the wants of the body satisfied. Thus the Kamschatdales are in the habit of mixing earth or saw-dust with the train-oil on which alone they are frequently reduced to live. The Veddahs or wild hunters of Ceylon, on the same principle, mingle the powdered fibres of soft and decayed wood with the honey on which they feed when meat is not to be had; and on one of them being asked the reason of the practice, he replied, "I cannot tell you, but I know that the belly must be filled." It has been found that soups and fluid diet are not more readily converted into chyme than solid aliment, and are not alone fit for the support of the body in health; and it is often to be observed, in disordered states of the stomach, that it can retain a small quantity of easily-digested solid food, when a thin broth would be rejected.

486. The sense of Satiety is the opposite of Hunger, and depends, like it, on two sets of conditions,—the state of the stomach, and that of the general system. It is produced in the first instance by the ingestion of solid matter into the stomach, which gives rise to the feeling of fulness; but this is only a part of the sensation which ought to be experienced; and it is only when the act of digestion is being duly performed, and nutritive matter is being absorbed into the vessels, that the peculiar feeling of satisfaction

is excited, which indicates that the wants of the system at large are being supplied. It has been very justly remarked by Dr. Beaumont, that the cessation of the demand set-up by the system, rather than the positive feeling of satiety, should be the guide in regulating the quantity of food taken into the stomach. The sense of satiety is beyond the point of healthful indulgence; and is Nature's earliest indication of an abuse and overburden of her powers to replenish the system. The proper intimation is the pleasurable sensation which is experienced when the cravings of the appetite are first allayed; since, if the stomach be sufficiently distended with wholesome food for this to be the case, it is next to certain that the digestion of that food will supply what is required for the nutrition of the body. It is only when the substance with which the stomach is distended is *not* of a digestible character, that the feelings excited by the state of that organ are anything but a correct index of the wants of the system.

487. The Pneumogastric is evidently the nerve which conveys to the Sensorium the impression of the state of the *stomach*, and which is therefore the immediate excitor of the sensation of hunger or of the feeling of satiety. But it is evident from experiments upon animals, that it is not the only source through which they are incited to take food, and are informed when they have ingested enough; and it is probable that the Sympathetic nerve is the channel through which the wants of the *system* are made known, and through which, in particular, the feeling of general exhaustion is excited, that is experienced when there has been an unusual waste, or when the proper supply has been too long withheld.

488. The conditions of the sense of Thirst are very analogous to those of hunger; that is, it indicates the deficiency of fluid in the body at large; but the immediate seat of the feeling is a part of the alimentary canal, — not the stomach, however, but the fauces. It is relieved by the introduction of fluid into the Circulating system through *any* channel; whilst the mere contact of fluid with the surface to which the sensation is referred, produces only a temporary effect unless absorption take-place. If liquids be introduced into the stomach by an œsophagus-tube, they are just as effectual in allaying thirst as if they were swallowed in the ordinary manner; and the same result follows the injection of fluid into the veins (as was most remarkably seen when this method of treatment was practised in Asiatic Cholera), or the absorption of fluid through the skin or the lower part of the alimentary canal. The deficiency of fluid in the body may arise, —and Thirst may consequently be induced,—either by an unusually-small supply of fluid, or by excessive loss of the fluids of the body, as by perspiration, diarrhœa, &c. But it may also be occasioned by the impression made by particular kinds of food or

drink upon the alimentary canal; thus salted or highly-spiced meat, fermented liquors when too little diluted, and other similar irritating agents, excite thirst; the purpose of which sensation is evidently to occasion the ingestion of fluid, by which these substances may be diluted, and their irritating action prevented.

CHAPTER V.

ABSORPTION AND SANGUIFICATION.

1. *Absorption from the Digestive Cavity.*

489. So long as the Alimentary matter is contained in the digestive cavity, it is as far from being conducive to the nutrition of the system, as if it were in contact with the external surface. It is only when absorbed into the vessels, and carried by the Circulating current into the remote portions of the body, that it really becomes useful in maintaining the vigour of the system, by replacing that which has decayed, and by affording the materials for the various organic processes which are continually going-on. Among the Invertebrated animals, we find the reception of alimentary matter into the circulating current to be entirely accomplished through the medium of the same system of vessels as that which conveys it through the body at large. We very commonly observe, indeed, that the Intestinal tube is completely enclosed within a large venous sinus, so that its whole external surface is bathed with blood; and into this sinus, the alimentary materials would appear to transude through the walls of the intestinal canal, to become mingled with the Blood and to be conveyed with its current into the remote portions of the body. Among the Vertebrata, we find that the Blood-vessels copiously distributed upon the walls of the Alimentary canal, constitute the channel by which a portion of the nutritive material is introduced into the system; but we also find an additional set of vessels interposed between the walls of the intestine and the sanguiferous system, for the purpose, as it would seem, of taking-up a special combination of nutritive materials, and of preparing this for being introduced into the current of the blood. These vessels—the *Lacteals* or *Absorbents*—are very copiously distributed upon the walls of the Small Intestine, commencing near the entrance of the Biliary and Pancreatic ducts; the walls of the Large Intestine are less abundantly supplied with them; and they do not show themselves in the villi which are found on some parts of

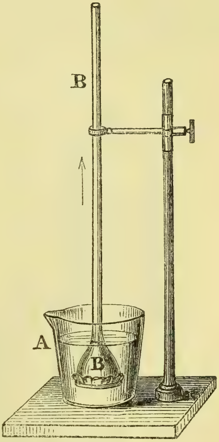
the lining membrane of the Stomach (§ 468), although the walls of that viscus are supplied with *lymphatic* absorbents.

490. Nevertheless it is quite certain, that substances may be taken into the current of the Circulation, which have been prevented from passing further than the Stomach; thus, if a solution of Epsom-salts be introduced into the stomach of an animal, and its passage into the intestine be prevented by a ligature around the pylorus, its purgative action will be exerted nearly as soon as if the communication between the stomach and intestines had been left quite free; or if a solution of prussiate of potash be introduced into the stomach under similar circumstances, the presence of that salt in the blood may be speedily demonstrated by chemical tests. It appears from the experiments of MM. Tiedemann and Gmelin, that when various substances were mingled with the food, which, by their colour, odour, or chemical properties might be easily detected, — such as gamboge, madder, rhubarb, camphor, musk, asafœtida, and saline compounds,—they were seldom found in the Chyle, though many of them were detected in the Blood and in the Urine. The colouring matter appeared to be seldom absorbed at all; the odorous substances were generally detected in the venous blood and in the urine, but not in the chyle; whilst, of the saline substances, many were found in the blood and in the urine, and only a very few in the chyle.

491. This passage of substances in a state of perfect solution, from the Alimentary canal into the Blood-vessels, is obviously due to the operation of that peculiar modification of Capillary Attraction, which is called *Osmosis*. When two fluids differing in density, but readily miscible with each other,—as Water, and an aqueous solution of Salt or Sugar,—are separated by a thin septum formed by an animal or vegetable membrane, or some other minutely porous medium capable of being wetted by both fluids, a strong current is found to set from the less dense towards the more dense fluid, the energy of which is (within certain limits) proportional to their difference of density. This is best shown by such a simple apparatus as that represented in Fig. 123, which consists of a tube, B, B, whose lower extremity, having the shape of an inverted funnel, is closed by a membrane tied over it; the fluid to be experimented-on being poured into the tube, so as to occupy the funnel-shaped portion, this is immersed in a vessel (A) of pure water. In a short time the fluid in the interior of the tube begins to rise, in consequence of the inward passage of a current of water, which is termed the *endosmotic* current; whilst, on the other hand, the water outside becomes charged with a portion of the salt or sugar of the interior fluid; and this mutual admixture will go-on until the density of the fluids on the two sides of the membrane has been equalized. The passage of the salt or sugar from the interior towards the exterior has been usually attributed

to the existence of an *exosmotic* current in the direction opposed to the endosmotic; but the recent experiments of Prof. Graham, Brücke, and others, render it probable that there is really no exosmotic *fluid* current, but that the particles of salt pass outwards by a process of solution in successive layers of the pure water contained in the membrane, until its outer surface is reached, when they immediately diffuse into the liquid around.—This tendency to *diffusion* of a substance in solution through water or some other liquid, or of one liquid (such as alcohol) through another (such as water) with which it is miscible in any proportion, has recently been investigated with great care by Prof. Graham; and he has arrived at the following very important conclusions. Certain substances, as the salts of the metals, generally pass through porous septa with facility; and these, with all substances so diffusing themselves, he terms 'crystalloids.' Other substances, as alumina, hydrated silicic acid, gum, dextrin, albuminous substances, &c., pass with great difficulty, or not at all; these he denominates 'colloids.' The latter are characterized by possessing very feeble chemical reactions; by diffusing very slowly in water; by having so weak an affinity for that liquid that they are easily precipitated from their solution; by being unable to pass by diffusion through any colloidal septum; by their consequent insipid taste (since they probably never reach the sentient extremities of the gustatory nerves); and by their high equivalent numbers, unstable nature, and ready passage into decomposition.

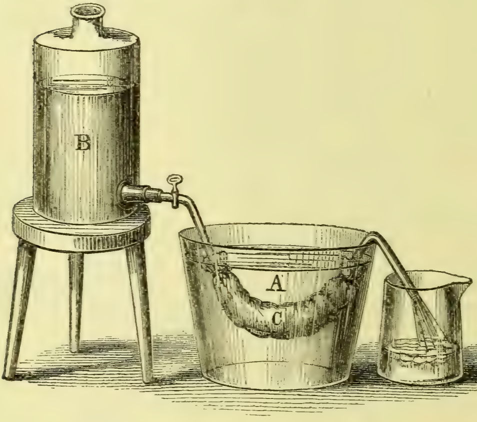
Fig. 123.



492. Although it is mainly on this tendency to 'diffusion' that the phenomenon of Endosmose depends, yet it can be easily shown to be greatly influenced by the power which the two liquids respectively possess of 'wetting' the porous septum. Thus when Alcohol and Water are on the opposite sides of a septum of bladder or other animal membrane, the current will pass from the water to the alcohol; but if the septum be of caoutchouc, the current will pass from the alcohol to the water;—the membrane being most readily transuded by water, and the caoutchouc

by Alcohol. Various other conditions influence the rapidity of the current; and among these there is none so powerful as *movement* of one of the fluids. Thus, if an apparatus be constructed on the plan shown in Fig. 124,—a portion C of the small intestine or of a large vein of an animal being attached at one extremity to a tube proceeding from the vessel B, and at the other extremity to a siphon, and immersed in a fluid filling the vessel A,—and if the vessel B and the tube C be filled with water, and the vessel A with water acidulated with sulphuric or hydrochloric acid, so

Fig. 124.



long as no current passes through the tube C, the transudation of the acidulated water to its interior will be very slow. But if, by opening the stopcock attached to the vessel B, a current of water be established through C, the presence of the acid is at once detectible in the water which flows out of it; and this will be especially the case if the outlet of the tube C be formed by a syphon (as in the figure) which tends to convey away the water more rapidly than it is supplied from the vessel B.—Now it seems to be in this manner that substances contained in the Alimentary canal, and perfectly dissolved by its fluids, are received into the Blood-vessels so copiously distributed on its walls: for as the blood is the fluid of greater density, it will have a tendency to draw towards itself the saline and other matters which are in a state of perfect solution in the cavity; and the movement of

blood through these vessels will tend to accelerate the permeation of liquids through the walls. Thus the continuance of the Circulation is obviously one of the most important of the conditions of Absorption. The substances thus directly absorbed must all be in the state of 'crystalloids,' in order to admit of their rapid penetration through the walls of the blood-vessels; but the process is by no means limited to saline and saccharine matters; for it has been ascertained by the experiments of Funke that, during the process of digestion, the organic substances belonging to the 'colloid' group are converted into 'crystalloids,' so as to be enabled to traverse animal membranes with comparative facility (§ 473).—The rapidity with which this Absorption of saline substances and their diffusion through the general current of the circulation may be effected, is well shown by the shortness of the time required under favourable circumstances for their passage into the excretions. Thus Mr. Erichsen found that he was able to detect the presence of ferrocyanide of potassium in the urine, within *one minute* after it had been swallowed in solution. This, however, was only when it was taken after a long fast; more commonly the absorption is less rapid; and if the substance be introduced within an hour or two after a full meal, as much as half an hour may elapse before its presence in the urine gives evidence of its having been received into the circulating current. Although Absorption takes place to a certain extent into the vessels of the Stomach, yet there can be no doubt that it is far more actively performed by the vessels of the Intestinal villi (Fig. 36), which present an enormous extension of vascular surface lying immediately beneath the basement-membrane. In Man, these villi are commonly cylindrical or nearly so, and are from about a quarter of a line to a line and a half in length; but in many of the lower animals they are spread-out into broader laminæ at the base, and are connected-together so as to form ridges or folds.

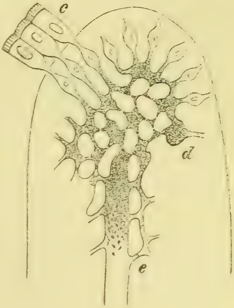
493. The nutritive materials thus taken-up by the Blood-vessels of the Alimentary canal, are not conveyed directly into the general circulation; for they are first submitted to the agency of the Liver. All the veins which return the blood from the gastro-intestinal capillaries, converge into the Portal trunk, which distributes it to the various portions of that secreting apparatus; and there is strong reason to believe that not merely is the fluid there *depurated* of some matters whose presence would be injurious, but that the Liver exercises a powerful *assimilating* action upon the proper nutritive substances, rendering them fitter to become components of the Blood. For the blood of the Portal vein, when examined during digestion, is found to contain a large proportion of an imperfect albumen, which appears to be the immediate product of the digestive operation; whilst, in that which

has passed through the liver, this is found to have given place to the proper albumen of the blood. Further, if white of egg mixed with water be injected into any of the Systemic veins, distinct evidence of the presence of albumen is speedily traceable in the urine, showing that this substance has not been properly assimilated; but if the same fluid be injected into the Portal system, no trace of its presence in the urine is found. So, again, when a solution of cane-sugar is injected into the general venous system, this substance soon shows itself in the urinary excretion; but if the same injection be made into the Portal vein, so that the sugar is obliged to pass through the liver, no such elimination of it takes-place, as it is then converted into a form of sugar which is more readily eliminated by the respiratory process (§ 174). The Liver, however, is not required to effect a corresponding change in the fatty matters taken-up from the food; for these are received into the blood through the Absorbents, rather than through the sanguiferous vessels; and it is found that if fatty matters be injected into the general circulation, no effect is produced on the urine. There is some reason to suppose that fatty matters may be elaborated in the liver, either from saccharine substances, or from albuminous compounds; but of this conversion there is at present no satisfactory evidence.

494. Every one of the intestinal Villi, however, also contains the commencement of a proper *lacteal* vessel; the portion of the Absorbent system specially adapted for the reception of alimentary matters from without, being thus distinguished, on account of the milky aspect of the fluid which is found within it. The Lacteal seems usually to commence either by a simple closed extremity, or by a loop; but in broad villi a sort of network is sometimes perceptible. When the villi are examined at such a period after a meal containing oleaginous matters as has sufficed for its partial digestion, their lacteals are seen to be turgid with chyle: the extremity of each being imbedded in a collection of globules presenting an opalescent appearance, and giving to the end of the villus a somewhat mulberry-like form. This appearance seems due to the distension of the cylindrical cells investing the villi (Fig. 125, *c*) with the lacteal fluid; these cells being the agents whereby the components of that fluid are selected from the contents of the alimentary canal. The free extremities of these cells present a peculiar longitudinally-striated appearance; which is considered by some eminent observers to indicate the presence of cilia, whilst others regard it as produced by fine pores or canals perforating the membrane that closes the extremity of the cell, and others, again, consider it as merely the optical expression of striæ or wrinkles, regarding the free extremity of the cell as closed only by a sort of plug of sarcodic substance. It seems to the Author most likely, on analogical grounds, that this last is

the nearest to the true account of the case; the 'germinal matter' of the cell being here but little limited by membrane, but being in almost as direct relation with the nutrient material it draws into itself from the contents of the Alimentary canal, as the sarcodic network of *Gromia* is with the water through which it is spread out (§ 200). There is reason to think that the small and attached extremities of these epithelium-cells are prolonged into the interior of the villi, and become continuous with the 'connective-tissue corpuscles' which seem to form a sort of sarcodic network through the extremity of the villus (Fig. 125); and that these again communicate with the plexus in which the lacteal originates. On this view, the Fatty and Albuminous particles taken up by the free sarcodic terminations of the epithelial cells, will be carried inwards to the lacteal that occupies the centre of the villus, by a circulatory movement of the sarcode resembling that which takes-place in the Rhizopods; and it is no small evidence in its favour, that solid particles, such as those of finely-divided Charcoal, Sulphur, and Starch, may be shown to find their way from the Alimentary canal into the current of the circulation.

Fig. 125.*



495. It is particularly important to keep in view the difference between the two modes by which Alimentary substances are introduced into the system, when we are treating those disordered states in which the digestive process is imperfectly performed, or is altogether suspended. There can be little doubt that the *immediate* cause of death, in many diseases of exhaustion, is the want of power to maintain the heat of the body; the stomach not being able to digest food, and the special absorbing power of the lacteals being entirely suspended, so that the inanition is as complete as if food were altogether withheld. Now, under such circumstances, it becomes a matter of the greatest importance to present a supply of combustible matter in such a form that it may be introduced into the circulating system by simple Endosmose; and the value which experience has assigned to broths and to *thin* farinaceous solutions, and still more, to diluted Alcoholic drinks, frequently

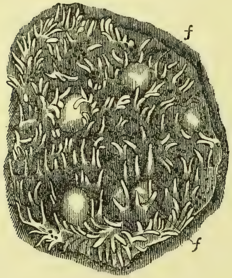
* Diagrammatic representation of the origin of the Lacteals in a Villus:— *e*, central lacteal; *d*, network of connective-tissue corpuscles; *c*, columnar epithelium-cells.

repeated, under such circumstances, seems to depend in great part upon the facility with which they may be thus absorbed. The good effects of alcohol, cautiously administered, are no doubt owing in part to its specific influence upon the nervous system; but that they are also due to its heat-producing power, appears from the results of the administration of frequently-repeated doses in states of utter exhaustion,—the temperature of the body being kept-up so long as they are continued, and falling when they are intermitted (§ 118). If the alcohol be thus burned-off nearly as fast as it is introduced, it will never accumulate in sufficient quantity to produce its usual violently-stimulating effects upon the nervous system.

2. *Passage of the Chyle along the Lacteals, and its admixture with the Lymph colleeted from the general System.*

496. The Lacteal vessels, which commence in the villi, run together at their base into a plexus which lies immediately beneath the follicles of Lieberkühn; and this communicates with another possessing larger vessels which are supplied with valves, more deeply situated in the sub-mucous connective tissue. From this last arise the larger trunks, which converge and unite with each other in the Mesentery.—In the midst of the Lacteal plexuses lie the peculiar bodies which are termed *Peyer's glands:* these may be either 'solitary' or 'agminated;' the former presenting themselves along nearly the whole length of the intestinal canal, whilst the latter are restricted to the small intestine, being most abundant at the lower part of the ileum. Each 'Peyerian body,' in a healthy mucous membrane, presents the appearance of a circular, white, slightly-raised spot, about a line in diameter, over which the membrane is usually less beset with villi, and is very often entirely destitute of them (Fig. 126); and it is surrounded by a ring of openings, which are the orifices of a set of cæcal follicles disposed in a zone around it. The wall of this body is not (as was formerly supposed) a proper membrane like that of a gland-vesicle, but is composed of distinctly-fibrillated connective

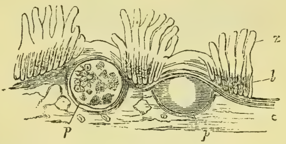
Fig. 126.*



* Surface-aspect of a portion of the Intestinal Mucous Membrane, showing the isolated Peyerian follicles, *f*, *f*, and the villi.

tissue, with interspersed nuclei; the substance which it encloses is a granular pulp, containing fatty and albuminous molecules of various sizes, with nuclear particles and a few cells (Fig. 127): and thus the entire corpuscle is far from being completely differentiated from the tissues in which the gland is imbedded. Each is surrounded by a close network of Blood-vessels, from which capillaries pass into the midst of its contents, returning thence by loops which re-enter the plexus. Although the Peyerian glandulæ are not penetrated by Lacteal vessels, yet there is evidence of their communication with the neighbouring Absorbents through spaces in the Connective tissue in which they are embedded; and it hence seems not improbable that they withdraw from those vessels, and return to them in a state of higher elaboration, materials newly absorbed; whilst their similarity in structure to the so-called Vascular Glands renders it likely that they also share in the function to which these are subservient, that of subjecting blood-plasma to the like elaborating action (§ 521).

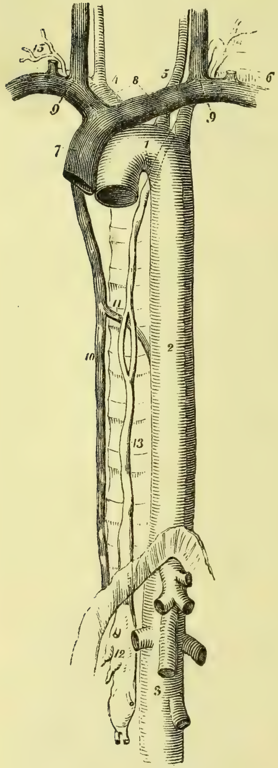
Fig. 127.*



497. In their passage across the Mesentery, the Lacteals enter certain bodies known as the Mesenteric glands. Each of these consists of a sheath or capsule of fibrous tissue, which sends inwards a large number of thin lamellæ, so disposed and connected together as to constitute a tolerably-regular framework pervading the outer portion of the glandule, and subdividing it into a number of rounded chambers or 'alveoli.' The central portion, on the other hand, is occupied by a 'medullary substance' much resembling the pulp of the Peyerian glands, and penetrated like it by capillary blood-vessels; this extends itself into prolongations of most irregular form and shape, which partly but do not entirely fill the alveoli; the spaces left being in such communication with the incurrent and excurrent Lacteals, that the fluid brought to the gland by the former must traverse both the peripheral extensions and the central mass of the pulp, before finding its way into the latter.—The structure of the so-called Absorbent glands which are found in like connection with the Lymphatic vessels, is in every essential respect the same; and we are presented with a sort of rudimental form of this glandular apparatus in the conglomerations of Lymphatics which occur in certain parts of the body, as the neck and the bend of the knee and elbow. The larger

* Vertical section of the Intestinal Mucous Membrane, bringing into view two Peyerian bodies:—*z*, villi; *l*, follicles of Lieberkühn; *m*, muscular coat: *c*, cellular coat; *p*, *p*, Peyerian capsules, one of them shown in section, the other not cut-open.

Fig. 128.*



trunks of the Lymphatics here occasionally break up into a dense interlacing network of small vessels, forming a *rete mirabile;* this is surrounded by condensed connective tissue, and it is penetrated by blood-vessels; and from this simple arrangement such a gradation can be traced to the complex structure of the gland, as shows that the latter is but a modification of the former. Hence the influence of the Glands upon the fluid that traverses them may fairly be supposed to be a more concentrated form of that which is diffused in a feebler degree through the entire Absorbent system.

498. After emerging from the Mesenteric glands, the Lacteal trunks converge, with occasional union, until they discharge their contents into the *Receptaculum chyli*, which is situated at the front of the body of the second lumbar vertebra (Fig. 128, 12). Into the same cavity are poured the contents of a part of the other division of the Absorbent system which is distributed through the body in general, and which, from the transparency of the fluid or lymph it contains, is termed the *Lymphatic* system. From the re-

* The course and termination of the Thoracic Duct:—1. the arch of the aorta; 2. the thoracic aorta: 3. the abdominal aorta, showing its principal branches divided near their origin; 4. the arteria innominata, dividing into the right carotid and right subclavian arteries; 5. the left carotid; 6. the left subclavian; 7. the superior cava, formed by the union of, 8, the two venæ innominatæ; and these by the junction, 9, of the internal jugular and subclavian vein at each side; 10. the greater vena azygos; 11. the termination of the lesser in the greater vena azygos; 12. the receptaculum chyli; several lymphatic trunks are now seen opening into it; 13. the thoracic duct, dividing opposite the middle of the dorsal vertebræ into two branches, which soon

ceptaculum chyli arises the *Thoracic duct* (13); which passes upwards in front of the spine, receiving other lymphatic trunks in its course, to terminate at the junction of the left subclavian and jugular veins; where it delivers its contents into the sanguiferous system (14). A smaller duct (15) receives some of the lymphatics of the right side, and there terminates at a corresponding part of the venous system; but it does not receive any of the contents of the lacteals.

499. The Lymphatic system is evidently allied very closely to the lacteal in its characters and general purposes; and makes its first appearance in the same class of animals, namely in Fishes. The vessels of which it is composed are distributed through the Connective tissue that holds together the other components of the Animal fabric (§ 226), and are particularly abundant in the Skin. They have never been found to commence by closed or open extremities; but appear to form a network from which the trunks arise; and this network seems to hold somewhat the same relation to the sarcodic substance of the 'connective-tissue-corpuscles' (§ 227) of the body generally, that the plexus at the extremities of the villi do to the corpuscles in the midst of which they lie. In their course, they pass through glandulæ disposed in different parts of the body, which exactly resemble in structure those found upon the lacteals in the mesentery (§ 497). And they at last terminate, as already shown, in the same general receptacle with the lacteals. Hence it cannot be reasonably doubted that the fluid which they absorb from the various organs of the body, is destined to become again subservient to nutrition; being poured-back into the current of the blood, along with the new materials which are now for the first time being introduced into it. That the special Absorbent apparatus of Vertebrated animals has for part of its function to effect a change in the materials absorbed, and thus to aid in fitting them for introduction into the blood, seems apparent from the facts of Comparative Anatomy; which show that the more distinct the Blood is from the Chyle and Lymph, the more marked is the provision for delaying the latter in the Absorbent system, and for subjecting it to preliminary change.

500. The course of the Absorbent vessels in *Fishes* is short and simple; they are not furnished with glands; and they pour their contents into the blood-vessels at several different parts of the body. In this class the blood contains fewer red corpuscles, and

reunite; the course of the duct behind the arch of the aorta and left subclavian artery is shown by a dotted line; 14, the duct making its turn at the root of the neck, and receiving several lymphatic trunks previously to terminating in the posterior aspect of the junction of the internal jugular and sub-clavian vein; 15, the termination of the trunk of the ductus lymphaticus dexter.

its coagulating power is feebler, than in any other Vertebrata. And in those lowest tribes in which the Vertebrated character is almost entirely wanting, and in which the blood is almost pale, no special Absorbent system has yet been discovered.—In *Reptiles*, the length of the Absorbent vessels is remarkably increased by their doublings and convolutions; so that the system appears to be more highly developed than in either of the warm-blooded classes. But this superiority is not real; for there is yet no trace of the Glands, which concentrate, as it were, the assimilative power of a long series of vessels. Moreover, we often find the lymphatics of this class furnished with pulsating dilatations, or *lymphatic hearts;* which have for their office to propel the lymph into the venous system. In the Frog there are two pairs of these, one situated just beneath the skin (through which its pulsations are readily seen in the living animal) immediately behind the hip-joint, the other pair being more deeply seated at the upper part of the chest. The former receive the lymph of the posterior part of the body, and pour it into the veins proceeding from the same part; the latter collect that which is transmitted from the anterior part of the body and head, and empty their contents into the jugular vein. Their pulsations are totally independent of the action of the heart and of the respiratory movements; since they continue after the removal of the former, and for an hour or two subsequently to the death and complete dismemberment of the animal. They usually take-place at the rate of about sixty in the minute; but they are by no means regular, and are not synchronous on the two sides.

501. In *Birds* we find the Absorbent system existing in a more perfect form; its diffused plexuses and convolutions being replaced by Glands, in which the contained fluid is brought into closer proximity with the blood, and in which it is subjected to the influence of assimilating cells. These glands, however, are not very numerous; being principally found on the lymphatics of the upper extremities. The absorbents, in this class, terminate principally by two thoracic ducts, one on each side, which enter the jugular veins by several orifices. There are, however, two other entrances, as in Reptiles, into the veins of the lower extremities; and these are connected with two large dilatations of the lymphatics, which are evidently analogous to the lymphatic hearts of Reptiles, but which have little or no power of spontaneous contraction.—It is in *Mammalia* that the Absorbent system presents itself in its most developed and concentrated state. The vessels possess firmer walls, and are more copiously provided with valves, than in the classes beneath; and the glands are much more numerous, particularly upon the vessels that receive or imbibe substances from without,—as those of the digestive cavity, the skin, and the lungs. The terminations of the absorbents in the veins are usually restricted, as in Man, to the single point of entrance of the Thoracic Duct on either side;

but they are sometimes more numerous; and certain variations in the arrangement of the thoracic ducts which occasionally present themselves as irregularities in Man, are the ordinary conditions of these parts in some of the lower Mammalia.

502. The contents of the Lymphatics, as we shall presently see (§ 505), bear a close resemblance to the fluid element of the blood, or 'liquor sanguinis,' in a state of dilution; and it may be considered as well ascertained that they partly consist of the residual fluid, which, having escaped from the Capillary blood-vessels into the tissues, and having furnished the latter with the materials of their nutrition, is now to be returned to the former. Such a transudation and re-collection of the serous portion of the Blood, constituting what has been well termed by Prof. Milne-Edwards an 'irrigation' of the tissues, is continually taking place in large amount (§ 503). But the Lymphatics may also take up those particles of the solid framework which have lost their vital powers, and which are therefore not fit to be retained as components of the living system, but which have not undergone a degree of decay that prevents them from serving, like matter derived from the dead bodies of *other* animals, as a material for reconstruction, when it has been again subjected to the organizing process.—Other substances, however, occasionally find their way into the Lymphatic system; thus, when the gall-bladder and bile-ducts are over-distended with bile, in consequence of some obstruction to its exit, the lymphatics of the liver are found to contain a biliary fluid. When the limb of an animal, round the upper part of which a bandage is tied, has been kept for some hours in tepid milk, the lymphatics of the skin are found distended with that fluid. And when saline solutions are applied to the skin, they are usually detected more readily in the lymphatics than in the veins. But these facts only prove that the lymphatics very readily imbibe soluble substances with which they are in proximity; and this imbibition seems to take-place on the same physical principles as the imbibition of soluble substances by the veins of the intestinal canal. The more ready absorption of such substances by the Lymphatics than by the Veins of the Cutaneous surfaces,—contrary to what obtains in the Alimentary canal,—is easily accounted-for by the very abundant distribution of the lymphatics in the skin, and the ready access which fluids can obtain to their walls. In other tissues it is different; thus it appears that saline matters injected into the Lungs are detected much sooner in the serum of the Blood than they are in the Lymph; and make their appearance earlier in the left cavities of the heart, to which they would be conveyed by the pulmonary vein, than in the right, which they would reach through the thoracic duct and descending cava. This is obviously due to the minute distribution of the blood-vessels upon the walls

of the air-cells; which make them far more ready channels for the imbibition of fluid than the lymphatics could be.—In the not unfrequent case of the absorption of pus by the Lymphatics, from the cavity of an abscess or of an open ulcer, it seems probable that the absorbent vessels are themselves laid-open by ulceration; since in no other way can we understand the entrance of globules so large as those of pus into their interior.

503. It may be stated, then, as a general proposition, that the function of the Absorbent system is to take up such materials as are fit to be applied to the purposes of nutrition, whether these be directly furnished by the aliment taken-in from without, or be drawn from the surplus-transudation of the fluid portion of the blood, or be derived from the disintegration of the organism itself. These materials they convey into the Sanguiferous system, but not without exerting upon them an Assimilating power; the fluid delivered by the Thoracic duct being (as will presently appear) very different in its properties from that which is first received into the Absorbent system. We may, in fact, regard the whole apparatus, with its connected glandulæ, as a great Assimilating Gland, the component parts of which are scattered, instead of being concentrated into one mass.—From the observations of Bidder and Schmidt it would appear that the total amount of fluid which is daily discharged by the Thoracic duct into the Subclavian vein, is no less than $28\frac{3}{4}$ lbs., or considerably more than the entire mass of the blood. Of the whole quantity thus discharged, it is estimated that only about $6\frac{1}{2}$ lbs. would be Chyle derived from the alimentary canal; the remaining $22\frac{1}{4}$ lbs. being Lymph which has passed out of the blood-current in the course of its circulation, to be returned to it again.

504. In regard to the cause of the movement of the Chyle and Lymph along the Absorbent vessels, from their commencement to their termination in the central receptacle, no very definite account can be given. The middle coat of these vessels has a fibrous texture, corresponding with that of certain forms of non-striated muscle (§ 332). In the Thoracic Duct this fibrous texture is more evident; and distinct contractions have been excited in it, by irritating the Sympathetic trunks from which it receives its nerves, and the roots of the Spinal nerves with which those trunks are connected Hence it seems probable that there is a sort of peristaltic contraction of the walls of the Absorbents, analogous to that which takes-place in the intestinal tube, serving to drive their contents slowly onwards; any reflux being prevented by the valves with which they are copiously furnished. Moreover, it is probable that the general movements of the body may concur with the contractile power of the absorbent vessels themselves, to urge their contents onwards; for almost every change in position must occasion increased pressure on some portion of them, which will

propel the fluid contents in the sole direction permitted by the valves, and thus give them an additional impulse towards the trunks, in which they are collected for delivery into the blood-vessels.

3. *Composition and Properties of Chyle and Lymph.*

505. The chief chemical difference between the Chyle and the Lymph, consists in the much smaller proportion of solid matter in the latter, and in the almost entire absence of fat which is an important constituent of the former. The Lymph obtained from the neck of a Horse having been analysed by Nasse, he found it to contain 95 per cent. of water; and the 5 per cent. of solid matter was chiefly composed of albumen and fibrin, with watery extractive,—scarcely a trace of fat being discoverable. The proportions of saline matter were found to be remarkably coincident with those which exist in the serum of the blood, as might be expected from the fact that the fluid portion of the lymph must have its origin in that which has transuded through the blood-vessels; the absolute quantity, however, is rather less. A similar analysis of the Chyle of a Cat by Nasse, gave the following results:—the proportion of water was 90·5 per cent.; and of the 9·5 parts of solid matter, the albumen, fibrin, and extractive amounted to more than 5, and the fat to more than 3 parts. This difference is also well shown in the following comparative analyses, performed by Dr. G. O. Rees, of the fluids obtained from the lacteal and lymphatic vessels of an Ass, previously to their entrance into the thoracic duct; the animal having had a full meal seven hours before its death:—

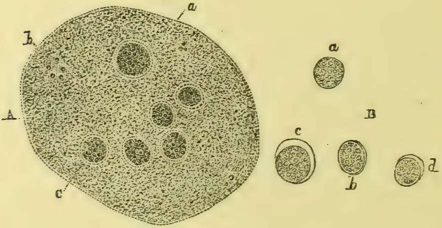
	Chyle.	*Lymph.*
Water	90·237	96·536
Albuminous matter (coagulable by heat) .	3·516	1·200
Fibrinous matter (spontaneously coagulable)	0·370	0·120
Animal extractive matter, soluble in water and alcohol	0·332	0·240
Animal extractive matter, soluble in water only	1·233	1·319
Fatty matter	3·601	a trace.
Salts;—Alkaline chloride, sulphate, and carbonate, with traces of alkaline phosphate, oxide of iron	0·711	0·585
	100·000	100·000

Dr. Rees also analysed the fluid of the Thoracic duct of Man, which consists of chyle with an admixture of lymph; and he found this to contain about 90·5 per cent. of water, 7 parts of albumen and fibrin, 1 part of aqueous alcoholic extractive, and

not quite 1 part of fatty matter, with about $\frac{1}{2}$ per cent. of salines. The composition of this fluid more resembled that of the Lymph than that of the Chyle; the proportion of the fatty to the albuminous matter being small. This was probably due to the circumstance that the subject from which it was obtained (an executed criminal) had eaten but little for some hours before his death.

506. The characters of the Chyle are not the same in every part of the Lacteal system; for the fluid undergoes a very important series of changes during its transit from the walls of the Intestines to the Receptaculum chyli. The fluid drawn from the lacteals that traverse the intestinal walls, has no power of spontaneous coagulation; whence we may infer that it contains little or no Fibrin. It contains Albumen in a state of complete solution, as we may ascertain by the influence of heat or of acids in producing coagulation. And it includes a quantity of Fatty matter, which is not dissolved, but suspended in the form of globules of variable size. The quantity of this evidently varies with the character of the food; it is more abundant, for instance, in the chyle of Man and the Carnivora, than in that of the Herbivora. It was formerly supposed that the milky colour of the chyle is owing to the oil-globules; but Mr. Gulliver has pointed-out that it is really due to an immense multitude of far more minute particles, which he has described under the name of the *molecular base* of the chyle (Fig. 127). These molecules are most abundant in rich, milky,

Fig. 127.*



opaque chyle; whilst in poorer chyle, which is semi-transparent, the particles float separately, and often exhibit the vivid motions

* Microscopic components of Human Chyle;—A, appearance of chyle as drawn from the thoracic duct, showing *a* the molecular base, *b* fat-particles, *c* chyle-corpuscles;—B, isolated corpuscles, showing at *a*, *b*, *c*, *d*, various stages in the development of the cell-membrane.

common to the most minute molecules of various substances. Such is their minuteness, that, even with the best instruments, it is impossible to determine either their form or their dimensions with exactness; they seem, however, to be generally spherical; and their diameter may be estimated at between 1-36,000th and 1-24,000th of an inch. Though remarkable for their unchangeableness, when submitted to the action of numerous re-agents which quickly affect the proper Chyle-corpuscles, their ready solubility in ether would seem to indicate that they are of an oily or fatty nature; and it is probable that each draws a coating of albuminous matter from the surrounding liquid, whereby their mutual coalescence is prevented.

507. The milky aspect which the serum of Blood sometimes exhibits, is due to an admixture of this 'molecular base.' It may be particularly noticed when blood is drawn a few hours after a full meal that has been preceded by a long fast. By experiments of this kind, it has been found that the serum begins to show this turbidity about half an hour after the meal has been taken; and that the turbidity increases for some hours subsequently, after which it disappears. The period at which the discolouration is greatest, and the length of time during which it continues, vary according to the digestibility of the food. When the serum is allowed to remain at rest, the opaque matter rises to the surface, presenting very much the appearance of cream; and when separately examined, it has been found to contain an albuminous compound, mingled with oily matter,—the relative amount of the two appearing to depend in part upon the characters of the food ingested. The gradual disappearance of the turbidity of the serum indicates that the substance which occasioned it no longer exists as such in the circulating current; being either drawn-off by the nutritive or secretory operations, or being converted by the assimilating process into the ordinary constituents of the blood.

508. During the passage of the Chyle along the lacteals towards the Mesenteric glands, it undergoes two important changes; the presence of fibrin begins to manifest itself by the spontaneous coagulability of the fluid; and the oil-globules diminish in proportional amount. The fibrin appears to be formed at the expense of the albumen; as this latter ingredient undergoes a slight diminution. It is in the chyle drawn from the neighbourhood of the mesenteric glands, that we first meet with the peculiar floating cells, or chyle-corpuscles (Fig. 127, B), formerly adverted-to (§ 214), in any number. The average diameter of these is about 1-4600th of an inch; but they vary from about 1-7000th to 1-2600th,—that is, from a diameter about half that of the human blood-corpuscles, to a size about one-third larger. This variation probably depends in great part upon the period of their growth. They are usually

minutely granulated on the surface, seldom exhibiting any regular nuclei, even when treated with acetic acid; but three or four central particles may sometimes be distinguished in the larger ones. These corpuscles are particularly abundant in the chyle obtained by puncturing the Mesenteric glands themselves; and there can be little doubt that they are identical with the nuclear particles, in various stages of development into cells, which those bodies contain (§ 497).

509. The glandular character of these cells, and their continued presence in the circulating fluid, seem to indicate that they have an important concern in the process of Assimilation,—that is, in the conversion of the crude elements derived from the food into the organizable matter adapted to the nutrition of the body; one part of this being the conversion of Albumen into Fibrin, which change would seem to take-place to a considerable extent in the Mesenteric glands. For it is only in the Chyle which is drawn from the lacteals intervening between the mesenteric glands and the receptaculum chyli, that the spontaneous coagulability of the fluid is so complete as to produce a perfect separation into *clot* and *serum*. The former is a consistent mass, which, when examined with the microscope, is found to include many of the chyle-corpuscles, each of them being surrounded with a delicate film of oil; the latter bears a close resemblance to the serum of the blood, but has some of the chyle-corpuscles suspended in it. Considerable differences present themselves, however, both in the perfection of the coagulation, and in its duration. Sometimes the chyle sets into a jelly-like mass; which, without any separation into coagulum and serum, liquefies again at the end of half an hour, and remains in this state. The coagulation is usually most complete in the fluid drawn from the receptaculum chyli and thoracic duct; and here the resemblance between the floating cells and the white or colourless corpuscles of the blood becomes very striking.

510. The Lymph, or fluid of the Lymphatics, differs from the Chyle, as already remarked, in its comparative transparence: its want of the opacity or opalescence which is characteristic of the latter, being due to the absence, not merely of oil-globules, but also of the 'molecular base.' It contains floating cells, which bear a close resemblance to those of the Chyle on the one hand, and to the colourless corpuscles of the Blood on the other; and these, as in the preceding case, are most numerous in the fluid drawn from the lymphatics which have passed through the glands, and in that obtained from the glands themselves. Lymph coagulates like chyle; a colourless clot being formed, which encloses the greater part of the corpuscles. The Lacteals may be regarded as the Lymphatics of the intestinal walls and mesentery; performing the function of interstitial absorption, as well as effecting the introduction of alimentary substances from without. During

the intervals of digestion, they contain a fluid which is in all respects conformable to the lymph of the lymphatic trunks.

511. Thus, by the admixture of the aliment newly-introduced from without, with the material which has been taken-up in the various parts of the system, and by the preparation which these undergo in their course towards the Thoracic Duct, a fluid is prepared, which bears a strong resemblance to blood in every particular save the presence of *red* corpuscles. Even these, however, may sometimes be found in the contents of the thoracic duct, in sufficient amount to communicate to them a perceptible red tinge. The fluid of the thoracic duct may be compared to the blood of Invertebrated animals, from which the red corpuscles are almost or altogether absent, but which contains white or colourless corpuscles, and which possesses but a slight coagulating power in consequence of its small proportion of fibrin. And we hence see why these animals should require no *special* absorbent system; since their blood-vessels convey a fluid which is itself so analogous to the chyle and lymph to be absorbed, that the latter may be at once introduced into it without injuring its qualities.

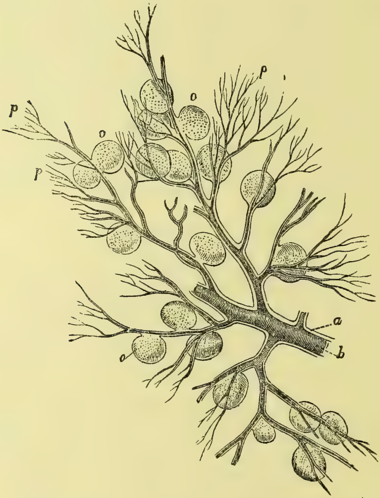
4. *Of the Vascular or Ductless Glands.*

512. The structure and functions of the Spleen, and of certain other organs allied to it in character, have been among the most obscure subjects in Anatomy and Physiology; and they are yet far from being fully understood. There seems sufficient evidence, however, for regarding these organs as concerned, like the Absorbent system, in the process of *Sanguification* or preparation of Blood.

513. The *Spleen* is probably to be regarded as an organ of compound structure, having more than one function to fulfil. It is essentially composed of a fibrous membrane, which constitutes its exterior envelope, and sends prolongations in all directions across its interior, so as to divide it into a number of minute cavities of irregular form, freely communicating with each other. In many animals, this fibrous envelope, and the prolongations or *trabeculæ* which it sends through the substance of the organ, are distinctly muscular; containing a large proportion of the peculiar fusiform contractile cells formerly described (§ 337). These, however, do not present themselves in the Human spleen; and its trabeculæ do not appear to have any contractile property. The areolæ formed by the trabecular tissue, commonly known as the *splenic follicles*, are differently occupied in different animals. In the Ruminants they are lined by a continuation of the splenic vein, which dilates into a cavernous structure, capable of receiving a very large quantity of blood. In Man, however, they have no communication with the splenic vein, and are chiefly occupied by the

Malpighian corpuscles and the parenchymatous tissue, which, in the Ruminants, are limited to the partitions between the venous cells. The Malpighian corpuscles of the spleen are whitish spherical bodies, which are always connected with the smaller arteries, like currants with their stalks (Fig. 130, *o*, *o*); being sometimes in immediate contact with them, but more commonly connected

Fig. 130.*



by a peduncle. Their size, when fully formed, varies from 1-3rd to 1-6th of a line. Each of them contains, as its constant and essential elements, nucleated cells from 1-4000th to 1-2500th of an inch in diameter, pale and faintly granular, together with free nuclei, as well as larger cells of 1-2000th of an inch in diameter, which sometimes contain what appear to be red blood-corpuscles. These are enclosed in a capsule which has no orifice, and which is precisely comparable to that of the Peyerian bodies (§ 496); and they are traversed by capillary blood-vessels after the same manner.

* Branch of the Splenic Artery with Malpighian Corpuscles attached;—*a*, sheath of artery; *b*, arterial branch; *p*, *p*, its penicillate subdivisions; *o*, *o*, Malpighian bodies.

The number and size of these bodies bear a remarkable relation to the general state of nutrition; being much the greatest in healthy well-fed animals, whilst in those that have been ill-fed they diminish extremely, and may even disappear altogether. The true *splenic parenchyma* consists in great part of cells which correspond in appearance with those of the Malpighian corpuscles; but in addition to these are found *coloured* cells, some of which are unchanged blood-corpuscles, whilst others appear to be blood-disks in various stages of retrograde metamorphosis. These components form small irregular groups of various sizes, which are clustered especially on the sheaths of the vessels, the trabecular partitions, and the exterior of the Malpighian capsules. The admixture of blood-disks seems accounted-for on the doctrine of Mr. H. Gray, that the splenic blood in its passage from the arteries into the veins normally escapes from the walled vessels into indefinite channels, so that its corpuscles may become diffused through the parenchyma without any departure from their regular course. The amount of *colourless* spleen-pulp varies, like that contained within the Malpighian corpuscles, in accordance with the general state of nutrition, and especially with the amount of albuminous matters in the blood; whilst the quantity of *red* spleen-pulp is proportional to that of red corpuscles which the blood may contain, being greatly augmented whenever there is a state of plethora, whilst it disappears altogether when the blood is at all poorer in red corpuscles than usual.

514. In regard to the functions of the Spleen, great uncertainty still exists. It appears from the foregoing account of its structure, that it may be regarded as an organ of duplex character, and probably of double function. In the Ruminants, the cavernous dilatations of the veins enable it to hold, upon occasion, a large quantity of blood; and their walls are so elastic, that their cavities may be greatly distended with a very moderate force; the Spleen of the sheep, which weighs about 4 oz., being easily made to contain about 30 oz. of water. This peculiar distensibility evidently points to the Spleen as a kind of reservoir connected with the Portal circulation, for the purpose of relieving the portal vessels from undue pressure or distension, under a great variety of circumstances. The portal system is in most animals destitute of valves, so that the splenic vein communicates freely with the whole of it; and thus if any obstruction exist to the flow of blood through the liver, or any peculiar pressure elsewhere should prevent the mesenteric veins from dilating to their full extent, the general circulation is not disturbed, the Spleen affording a kind of safety-valve. That any cause of congestion of the Portal system peculiarly affects the Spleen, has been proved by experiment; for, after the portal vein has been tied, the spleen of an animal that previously weighed only 2 oz., has been found to

increase to 20 oz.—Again, the Spleen appears to serve as a reservoir into which superfluous blood may be carried during the digestive process. When the alimentary canal is distended with food, and a great afflux of arterial blood takes place to the mucous membrane, the veins of the portal system will be liable to increased pressure from without, whilst their contents will be augmented by the quantity of fluid newly absorbed from the alimentary canal. In this, as in the preceding cases, the distensibility of the spleen makes it a kind of safety-valve, by which undue distension of the portal system is relieved. It has been ascertained that its maximum volume is attained about five hours after a meal, when the process of chymification is at an end, and that of absorption is taking-place with activity; and the increase is proportional rather to the amount of the fluids ingested, than to that of the solids.—Although the Human Spleen has no true cavernous structure, yet its veins are obviously very distensible, so that a great accumulation of blood may take-place in it. Thus, in Asphyxia, when the circulation of blood is checked in the Lungs, and when the stagnation extends itself backwards to the right side of the heart, to the vena cava, and thence to the portal system, the Spleen is often found after death to be enormously distended with blood. And in the cold stage of intermittent fever, in which a great quantity of blood is driven from the surface towards the internal organs, the Spleen receives a large portion of it, so that its increased size becomes quite perceptible; and in cases of confirmed Ague, the Spleen becomes permanently enlarged, forming what is popularly known as the 'ague-cake.'

515. But there can be little question that this safety-valve function is supplemental to some other, which is related more closely to the nutritive operations, and which in some degree corresponds with that performed by the Absorbent glandulæ. The multitude of glandular cells in immediate relation with blood-vessels, and the appearances of rapid development and degeneration which these present, taken in connection with the fact that there is no other outlet for the products of their action than that which is afforded by the veins, clearly indicate that whatever this product may be, it is destined to form part of the blood; and that the Spleen is, therefore, an organ of sanguification. This view is confirmed by the remarkable fact, ascertained by recent experiments, that after the spleen has been extirpated, the lymphatic glands of the neighbourhood increase in size, and cluster-together as they enlarge, so as to form an organ which at least equals the original spleen in volume. This circumstance explains the reason of the almost invariable *negative* result of the extirpation of the spleen; for although the operation has been frequently practised, with the view of determining the functions of the organ by the symptoms presented by the animals after its removal, no decided

change in the ordinary course of their vital phenomena has ever been observed, and the health, if at all disturbed for a time, is afterwards completely regained. Now if the principal function of the Spleen be the same with that of the Assimilating glands in general, it is easy to understand how its loss may be at once compensated by an increased action on their part, and how it may be permanently replaced by an increased development of certain of those bodies.

516. It would further seem as if the Spleen were specially concerned in the *development* of the Red corpuscles of the blood; since its parenchyma contains cells which resemble these in various stages of development, and similar cells are found, sometimes in considerable abundance, in the blood of the splenic vein. But this organ also appears, under certain circumstances, to promote the *disintegration* of the Red corpuscles; and this so powerfully, that the blood of the splenic vein may contain a far *less* proportion of red corpuscles, as well as a far *greater* proportion of albumen, than that of any other vessels in the body. This happens when the red corpuscles are in excess; and hence it seems as if the organ were destined to exert a regulative action upon their amount; supplying them when they are deficient, and getting rid of them when they are over-abundant.

517. The *Supra-Renal Capsules* seem to correspond with the Spleen in their essential structure, whilst in the arrangement of their component parts they bear more resemblance to the Kidney; a *cortical* being distinguished from a *medullary* portion in Man and the Mammalia generally, though not in the lower Vertebrata. The difference chiefly consists in the arrangement of the fibrous *stroma*, and in the distribution of the Blood-vessels. In the cortical portion, the fibrous tissue passes inwards in straight nearly parallel bands, so arranged as to leave a series of oval spaces lying end to end; in the medullary the fibrous stroma is less abundant and is disposed on no regular plan. The arteries of the cortical substance pass inwards nearly in straight lines, and divide into a minute capillary network, from which arise venous branches that form a minute plexus through the medullary substance, pouring its contents into a large central cavity, which is the dilated commencement of the supra-renal vein. The interspaces of the fibrous stroma and vascular plexus are occupied by a finely granular plasma, containing a large amount of fat-particles, with cells in various stages of development; and there is some reason to think that the cells of the medullary substance are really *ganglionic* in character.—The Supra-Renal capsules of Man attain a very large size in early fœtal life, surpassing the true Kidneys in dimension up to the tenth or twelfth week; but they afterwards diminish relatively to the latter, and are evidently subordinate organs during the whole remainder of life. In most of the lower

animals, however, these bodies retain through life the same relative development.

518. The *Thymus Gland* is another body which seems referable to the same group, having the essential characters of a true gland (§ 714) save an excretory duct; and its function being evidently connected, during the early period of life at least, with the elaboration of nutritive matter, which is to be re-introduced into the circulating current. Its elementary structure may be best understood from the simple form it presents, when it is first capable of being distinguished in the embryo. It then consists of a single tube, closed at *both* ends, and filled with granular matter; and its subsequent development consists in the lateral growth of branching off-shoots from this central tubular axis. In its mature state, therefore, it consists of an assemblage of hollow granular lobules, united by connective tissue, and surrounded by a plexus of blood-vessels; and their cavities all communicate with the central reservoir, from which, however, there is no outlet. Each lobule is bounded by an indistinctly-fibrous or almost homogeneous membrane, which is lined by a greyish-white pulp consisting of free nuclei and minute cells, and is traversed by a minutely distributed capillary plexus; and it thus corresponds in every particular, save the presence of a central cavity, with a Peyerian or Malpighian corpuscle. Cells and nuclei resembling those of the parenchyma, are found in the cavity of the lobule; from which, indeed, the parenchyma is not separated by any distinct limitary membrane. The chemical composition of this pulpy substance corresponds with that of the ordinary albuminous compounds.—The Thymus has been commonly said to attain its greatest development, in relation to the rest of the body, during the latter part of fœtal life; and it has been considered as an organ peculiarly connected with the embryonic condition. But this is a mistake; for the greatest activity in the growth of this organ manifests itself, in the Human infant, soon after birth; and it is then, too, that its functional energy seems the greatest. This rapid state of growth, however, soon subsides into one of less activity, which merely serves to keep-up its proportion to the rest of the body; and its increase usually ceases altogether at the age of about two years. From that time, during a variable number of years, it remains stationary in point of size; but if the individual be adequately nourished, it gradually assumes the character of a mass of fat, by the development of the corpuscles of its interior into fat-cells, which secrete adipose matter from the blood. This change in its function is most remarkable in hybernating Mammals; in which the development of the organ continues, even in an increased ratio, until the animal reaches adult age, when it includes a large quantity of fatty matter. The same is the case, generally speaking, among Reptiles.

519. Various facts lead to the conclusion that the function of

the Thymus, at the period of its highest development, is that of elaborating and storing-up nutritive materials, to supply the demand which is peculiarly active during the early period of extra-uterine life. The elaborating action probably corresponds with that which is exerted by the glands of the Absorbent system; and the product, as in the preceding cases, seems to be taken-back into the circulation. The provision of a store of nutritive matter seems a most valuable one, under the circumstances in which it is met-with; the waste being more rapid and variable than in adults, and the supply not constant. Thus it has been noticed that, in over-driven lambs, the thymus soon shrinks remarkably; but that it becomes as quickly distended again during rest and plentiful nourishment. As the demand becomes less energetic, and as the supplies furnished by other organs become more adequate to meet it, the Thymus diminishes in size, and no longer performs the same function. It then obviously serves to provide a store of material, not for the nutrition of the body, but for the respiratory process, when this has to be carried-on for long periods (as in hybernating Mammals, and in Reptiles) without a fresh supply of food.

520. The *Thyroid* Gland bears a general analogy to the Thymus; but its vesicles are distinct from each other, and do not communicate with any common reservoir. They are surrounded, like the vesicles of the true glands, with a minute capillary plexus; and in the fluid they contain numerous corpuscles are found suspended, which appear to be cell-nuclei in a state of more or less advanced development. This body is supplied with arteries of considerable size, and with peculiarly large lymphatics. Though proportionally larger in the fœtus than in the adult, it remains of considerable size during the whole of life.—It appears from the inquiries of Mr. Simon that a Thyroid gland, or some organ representing it in place and office, exists in all Vertebrated animals. It presents its simplest form in the class of Fishes; in some of which it appears to consist merely of a plexus of capillary vessels, connected with the origin of the cerebral vessels, and capable, by its distensibility, of relieving the latter, in case of any obstruction to the proper movement of blood through them. In the higher forms of this organ, the glandular structure,—consisting of the closed vesicles over which the capillary plexus is distributed, and of their cellular contents,—is superadded: and the organ then appears, like the Spleen, to be destined for two different uses; namely, to serve as a *diverticulum* to the Cerebral circulation, and to aid in the elaboration of nutritive matter, which is probably taken-up by the Absorbent system, to be again poured by it into the general current of the circulation.

521. Thus the Peyerian bodies, Spleen, Supra-Renal capsules, Thymus gland, and Thyroid gland, all seem to share in the preparation of the nutritive materials of the Blood; withdrawing certain

of its constituents, to restore them to the circulating current in a state of more complete preparation for the operations of Nutrition. In fact we may regard them all as together constituting an elaborating apparatus essentially analogous to that of the ordinary Glands; but of which the elementary parts are scattered through the body, instead of being collected into one compact structure; and of which the product is received-back into the blood, instead of being discharged through an efferent duct upon the surface of the body or into an open cavity. It is obvious, from the very copious supply of Blood which these organs receive during the period of their functional vigour, and from the manner in which this is distributed through their substance, that it must be subservient to some purpose of active change; and the aspect of their parenchymatous substance indicates that cell-formation is rapidly proceeding at the expense of the materials derived from the circulating current. But, on the other hand, that the products of this action are not substances to be separated from the Blood, either for *its* purification, or to serve some special purpose in the economy, appears from the fact that they are not carried off by ducts, but are received again into the Vascular system. Their function is very probably *vicarious;* that is, the determination of blood is greatest (through the state of the other organs) at one time to one of these bodies, and at another time to another. Hence the effects of the loss of any one of them are not serious; as the others are enabled in great degree to discharge its duty.

5. *Absorption from the External and Pulmonary Surface.*

522. Although the Mucous Membrane of the Alimentary Canal is the *special* channel for the introduction of nutritive or other substances into the system, it is by no means the *only* one. The Skin covering the body, and the Mucous Membrane prolonged into the Lungs, are also capable of absorbing liquids and vapours, and of introducing them into the Circulation; although they serve this purpose less in Man and the higher animals, than in some of the lower. Their utility in this respect is best shown, when, from peculiar circumstances, the function of the digestive cavity cannot be properly performed; and when, therefore, the system has been more than usually drained of its fluids, and stands in need of a fresh supply.—Thus shipwrecked sailors and others who are suffering from thirst owing to the want of fresh water, find it greatly alleviated, or altogether relieved, by dipping their clothes into the sea and putting them on whilst still wet, or by frequently immersing their own bodies. In a case of Dysphagia, in which neither solid nor fluid nutriment could be introduced into the stomach, the patient was kept alive for a considerable time, and his sufferings greatly alleviated, by the administration of nutritive clysters, and by the immersion of his body in a bath of tepid milk and water, night and morning.

Under this system, the weight of the body, which had previously been rapidly diminishing, remained stationary, although the amount of the excretions was increased; and the use of the bath had a special influence in assuaging the thirst, which was previously distressing. It appeared that the water of the urinary excretion, amounting to from 24 oz. to 36 oz. per day, must have been entirely supplied from this latter source. Again, a man who had lost nearly 3 lbs. by perspiration, during an hour and a quarter's labour in a very hot atmosphere, regained 8 oz. by immersion in a warm bath at 95° for half an hour.—In these cases, it appears probable, from the experiments already noticed (§ 502), that the Lymphatics rather than the blood-vessels are the chief agents in the absorbing process; not, however, from any powers peculiar to them, but merely on account of the thinness of their walls, and their very copious distribution in the skin.

523. Absorption may also take place from an atmosphere saturated with watery vapour. Of this we have a very curious proof in the Frog; whose urinary bladder (which serves as a sort of reservoir of water) has been observed to be refilled, after having been emptied, by placing the animal in an atmosphere loaded with watery vapour. Numerous instances are on record, which prove that such absorption may take-place in Man to a very considerable extent; though the proportions introduced through the Skin and through the Lungs respectively cannot be exactly ascertained. The ready introduction of volatile matter into the system through the latter channel, is a matter of familiar experience; thus if we breathe an atmosphere through which the vapour of turpentine is diffused, it soon produces the characteristic odour of violets in the urinary secretion. And it is probably in this manner that a large number of those putrescent miasmata and other zymotic poisons are introduced, which are such fertile causes of disease.

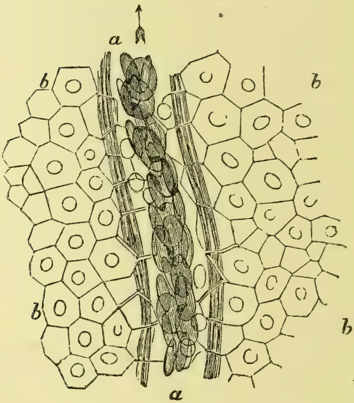
6. *Of the Composition and Properties of the Blood.*

524. Having traced the steps by which the Blood is elaborated, and prepared for circulation through the body, and having (in the former part of the volume) inquired into the characters of its chief constituents, we have now to consider the fluid as a whole, to study the usual proportions of these constituents, and the properties which they impart to it.—The Blood, in its ordinary condition, when drawn *en masse* from the vessels of the living body, is a thick opaque liquid, varying in colour, according to the part of the Circulating system from which it is drawn, from a brilliant scarlet to a dark purple. It has a slightly alkaline reaction, and a specific gravity of about 1055. The total weight of Blood in Man would appear, from the careful estimate of Weber and Lehmann to be about *one-eighth* that of the body; so that the

body of a healthy Man weighing 140 lbs. will probably contain about $17\frac{1}{2}$ lbs. of Blood.

525. If the Circulation in the smaller vessels be examined with the Microscope, the Blood may be seen to consist of a transparent, nearly colourless fluid, termed *Liquor Sanguinis;* wherein the *Corpuscles* to which the blood owes its *red* hue, as well as the white or *colourless* corpuscles, are freely suspended and carried along by the current (Fig. 131).—On the other hand, when the

Fig. 131.*



blood has been drawn from the body, and is allowed to remain at rest, a spontaneous coagulation takes place, separating it into Clot and Serum. The Clot is composed of a network of *Fibrin*, in the meshes of which the *Corpuscles*, both red and colourless, are involved; and the Serum is the same with the liquor sanguinis deprived of its fibrin. When the serum is heated, it coagulates, showing the presence of *Albumen.* And if it be exposed to a high temperature, sufficient to decompose the animal matter, a considerable amount of earthy and alkaline *Salts* remains.—Thus we have four principal components in the Blood;—namely, Fibrin,

* A small Venous trunk, *a*, from the web of the Frog's foot, showing the central part occupied by files of oval Blood-disks, carried along in a stream of transparent Liquor Sanguinis, in which the round transparent Colourless corpuscles are seen; *b*, *b*, cells of pavement-epithelium.

Albumen, Corpuscles, and Saline matter. In the *circulating* Blood they are thus combined:—

Fibrin Albumen Salts	In solution, forming Liquor Sanguinis.
Red Corpuscles	Suspended in Liquor Sanguinis.

But in *coagulated* blood they are thus combined:—

Fibrin Red Corpuscles	Crassamentum or Clot.
Albumen Salts	Remaining in solution, forming Serum.

A certain amount of Serum, however, is involved in the Crassamentum; and can only be separated by cutting the clot into thin slices, and carefully washing it.—The Red Corpuscles are considerably heavier than the fluid in which they are suspended; their normal specific gravity being in Man about 1089, while that of the Serum averages 1028.

526. The components of the Blood may be separated, and their amount estimated, in various ways. Thus, if fresh-drawn blood be continually stirred with a stick, or be 'whipped' with a bunch of twigs, the Fibrin coagulates in the form of strings, which adhere to the wood and may thus be withdrawn; whilst the red corpuscles remain suspended in the serum, gradually sinking to the bottom in virtue of their greater specific gravity.—On the other hand, the Red Corpuscles may be separated, in those animals in which they are large enough, by passing the blood through a filter; having previously mingled with it some substance which retards but does not prevent its coagulation (§ 190).* The liquor sanguinis is thus separated from the blood-disks; and the former coagulates, whilst the blood-disks are retained upon the filter.—By these modes the composition of the Serum and the Red Corpuscles can be studied separately, and the proportions of their components determined.—Each of these constituents of the Blood contains *Saline* substances, which may be obtained by incinerating their solid residua; and these are by no means the same in the Red Corpuscles and in the Liquor Sanguinis (§ 528).—The solid matter of the blood also contains various *Fatty* substances, which may be removed from it by ether. Some of these appear to correspond with the constituents of ordinary Fat (§ 176); whilst another contains phosphorus, and seems allied to the peculiar fatty acids of Nerve-substance (§ 383); and another

* This experiment cannot be performed with Human blood, because the corpuscles are small enough to pass through the pores of any filter that allows the liquor sanguinis to permeate it; but it answers very well with Frog's blood.

has some of the properties of Cholesterine, the fatty matter of the Bile (§ 724).—Besides these, there are certain substances known under the name of *Extractive;* one group of which is soluble in Water, and another in Alcohol. Of the precise nature of these, little is known. They have been aptly termed 'ill-defined' animal principles; and it is probable that they may include various substances in a state of change or disintegration, which are being eliminated from the Blood by the processes of Excretion. The advance of Chemical knowledge, however, is gradually leading to the detection of definitely-known substances in the extractive of the blood; especially of those excretory matters which are destined for elimination by the Kidneys, such as urea, uric acid, creatine, creatinine, and hippuric acid.

527. The general result of numerous recent analyses of the Blood may be thus stated:*—The whole amount of solid matter is rather greater in the Male than in the Female; being, on the average, about 210 parts in 1000 in the former, and 190 in the latter. This difference, however, chiefly depends on the larger proportion of Red Corpuscles contained in the blood of the male. The proportion of Albumen seems more constant than that of the other constituents of Blood; seldom varying beyond 5 or 6 parts, in either sex, above or below 70 in 1000.—The quantity of Corpuscles appears liable to considerably greater variation; the superiority on the side of the Male, however, being very strongly marked in the maximum and minimum, as well as in the average. We may regard its average in the Male as about 132 in 1000 parts of blood; but it may fall to 110·5 parts without the health being seriously affected, whilst on the other hand it may rise to 186 without any manifestation of disease. In the Female, its average may be about 120 parts in 1000; but it may fall to as little as

* The proportions above given are those commonly assigned on the basis of analyses made by Prof. Andral's method. They are, however, subject to the fallacy, that all the water of the Corpuscles is computed as holding in solution the solids of the Serum; and the latter are consequently estimated too high, whilst the solids of the Corpuscles are reduced to a lower proportion than they really bear. According to the estimates of Schmidt and Lehmann, based on separate analyses of the Corpuscles and of the Liquor Sanguinis, when the total volume of *moist* Corpuscles is 50 per cent. of the entire volume of the blood (which may be considered as about an average proportion), the relative amounts of *dry* solids will be, in round numbers, as follows:—

Fibrin	2
Corpuscles	150
Albumen	40
Fatty and Extractive Matters	5
Salts	8
Total Solids	205
Water	795
	1000

71·4, and may rise to 167, consistently with ordinary health. The range of variation is thus much greater in the Female than in the Male; the minimum in the former being considerably less than half the maximum, whilst in the latter it is much more. This is probably due in part to the fact, that the loss by the Catamenial discharge may produce a great temporary depression in the proportion of the Corpuscles.—The average proportion of Fibrin seems to be no more than 2·5 in the Male; and though it may rise to as much as 3·5 or even 4, without disordering the system, it does not seem to fall below 2, in the state of ordinary health. The average in the Female is probably about 2·3; the proportion may rise to 3, or fall to 1·8; but the variation seems less considerable in the Female than in the Male.—Much is probably yet to be learned regarding the influence of different kinds of food recently taken on the proportion of these constituents of the blood; and it does not seem unlikely from what has been already stated (§ 517), that the quantity of fatty matter is especially liable to variation, in accordance with the amount contained in the food, and the time which has elapsed since the last meal.

528. The Saline constituents of the blood, obtained by drying and incinerating the whole mass, usually amount to about 8 parts in 1000. More than half of their total quantity is composed of the Chlorides of Sodium and Potassium; and the remainder is made-up of the tribasic Phosphate of Soda, the Phosphates of Lime and Magnesia, Sulphate of Soda, and a little Phosphate and Oxide of Iron. The Chloride of Sodium is almost entirely contained in the Liquor Sanguinis; whilst the Potass of the blood is almost wholly included in the Red Corpuscles. The Iron, which amounts to about 1·17 part, is limited to the Corpuscles. And as the Phosphorus of the Corpuscles is to that of Liquor Sanguinis as 6 to 1, and as there is also a considerably larger proportion of Fat in the Corpuscles than in the Liquor Sanguinis, there seems good reason to believe that it is in them that the peculiar 'phosphorized fats' of Nerve-substance are elaborated.—It is uncertain whether the Alkaline reaction of the Blood is in any degree due to the presence of alkaline carbonates; certainly it is in part dependent upon the presence of the tribasic phosphate of soda, which appears to confer upon the Serum a special power of absorbing carbonic acid.

529. The following appear to be the chief uses of the principal constituents of the Blood in the general economy.—The Fibrin was formerly supposed to be the immediate pabulum of the tissues generally, and of muscle in particular; but there seems to be now much reason to limit its utility to the production of those simple forms of fibroid substance, the production of which is the first step in the reparation of injuries (§ 188). It is entirely on the coagulating

power of the Fibrin, that the cessation of hemorrhage from even the most trifling wounds, the limitation of purulent effusions by the consolidation of the surrounding tissue, the separation of gangrenous parts without escape of blood, the adhesion of incised wounds, and the first filling-up of breaches of substance, are all alike dependent. Moreover, if a proper amount of Fibrin be not present in the Blood, the physical properties of the liquid are so far altered by the diminution of its viscidity, that it will not circulate through the capillaries as readily as before; a certain degree of viscidity having been experimentally found to be favourable to the movement of fluid through glass or metallic tubes of small bore.—The Albumen of the blood is the raw material from which not only its Fibrin, but many other substances are generated during the nutritive process; since it is probably at the immediate expense of this component of the blood, intimately combined with Fat, that the tissues of the body are developed, as they are in the Ovum at the expense of the store of Albumen and Fat laid-up in it. Further, all the Albuminous compounds of the Secretions, the Horny matter of the Epidermic tissues, the solid materials of the Red Corpuscles, and other substances, may be regarded as almost certainly produced by the transformation of the Albumen of the Blood; and a continual supply of this from the food is therefore requisite, to preserve the due proportion in the circulating fluid.

530. The Red Corpuscles have undoubtedly a far greater absorptive power for Oxygen than is possessed by the fluid in which they float; for defibrinated blood, which contains the corpuscles, absorbs nearly 20 per cent. of oxygen; whilst serum deprived of corpuscles absorbs very little more than water, which takes-up less than 3 per cent. of oxygen. This circumstance, taken in connection with the fact that these bodies are almost completely restricted to the blood of Vertebrata (whose respiration is much more energetic than that of any Invertebrated animals save Insects, which have a special provision of a different character), and that their proportion to the whole mass of the blood corresponds with the activity of the respiratory function,—leave little doubt that they are actively (though not exclusively) concerned as *carriers* of Oxygen from the lungs to the tissues, especially to the Nervous and Muscular, the activity of which we have seen to depend upon the supply of Oxygen furnished by Arterial blood. It is conformable to this view of their function, that their presence is more effectual in stimulating the Heart's action, than is that of either of the other constituents of the blood. What may be the relation of the Red Corpuscles, however, to the function of Nutrition, is more questionable. But it can scarcely be regarded as otherwise than a very significant circumstance, that the phosphorized fats which seem destined to form the

pabulum of the Nervous tissue, and the potass which is a most characteristic component of the Muscular, should be almost entirely limited to their contents, being scarcely discoverable in the serum. The grey matter of the Nervous centres, moreover, in common with Muscular fibre generally, contains a pigmentary matter closely allied to Hæmatin. Hence it seems not altogether improbable, that the Red corpuscles may have it as one of their offices to prepare the nutrient materials for these tissues by an assimilating process; and this idea is also in accordance with the fact, that they are most numerous in those Vertebrata which are most distinguished by their nervo-muscular activity.

531. The use of the Saline matter is evidently in part to prevent decomposition in the circulating Blood, but also to supply the mineral materials requisite for the generation of the tissues and entering into the composition of the secretions. It is by the saline and albuminous matters in conjunction, that the specific gravity of the Liquor Sanguinis is kept-up to the point at which it is equivalent to that of the contents of the Red Corpuscles; this being a condition essential to the due maintenance of the latter (§ 216).—Of the Fatty matters of the Blood, a large proportion is certainly appropriated to the maintenance of the combustive process. But it is no less certain that Oleaginous matter performs a most important part in the incipient stages of Animal nutrition; and that its presence is not less essential in the organizable blastema, than is that of the albuminous matter which forms its chief component, all *nuclei* being observed to include fatty particles. That which may be superfluous is either deposited in the cells of Adipose Tissue, or is eliminated by the Sebaceous follicles of the Skin, and in the female when nursing by the Mammary glands.

532. The Coagulation of the Blood, as already explained, depends upon the passage of its Fibrin from the fluid state to the solid (§ 189); consequently, if the fibrin be separated from the other components, no coagulation takes place. On the other hand, if the amount of fibrin be larger than ordinary, the coagulum possesses an unusual degree of firmness. The length of time which elapses before coagulation, and the degree in which the clot solidifies, vary considerably; in general they are in an inverse proportion to each other. Thus, if a large quantity of blood be withdrawn from the vessels of an animal at the same time, or within short intervals, the portions that last flow coagulate much more rapidly but much less firmly than those first obtained, in consequence of the diminished proportion of fibrin. On the other hand, when the fibrin is in excess, its coagulation is usually delayed. From this delay an important change results in the mode in which the coagulation takes-place; for the red corpuscles, instead of being uniformly diffused through the coagulum, have

time to sink to the bottom, in virtue of their greater specific gravity; and the upper part of the clot is consequently made-up almost exclusively of a Fibrinous network entangling the Colourless corpuscles (Fig. 3); whilst the lower is chiefly formed by the aggregation of the Red corpuscles. Hence the upper layer is almost destitute of colour (whence it has received the name of *buffy coat*), and is remarkably tenacious in its character; whilst the lower is very deep in hue, and very friable in consistence. When the fibrillated network forming the buffy coat undergoes that slow contraction which is characteristic of highly-elaborated Fibrin subsequently to its coagulation, it draws-in the edges of the upper surface of the clot, giving it a *cupped* appearance.

533. The Buffy Coat may present itself under a great variety of conditions; and it can no longer, therefore, be considered (as it formerly was) a sign of the Inflammatory state, in which there is an excess of Fibrin in the blood. Thus it may be produced by any cause which occasions delay in the coagulation; as is evident from the fact that healthy blood may be made to exhibit it by adding a solution of a neutral salt, which retards but does not prevent its coagulation. It may occur, moreover, without any absolute excess of Fibrin in the blood, but simply from its excess in relation to the amount of Red Corpuscles, the latter being much below their usual proportion. Thus in severe Chlorosis, the buffy coat is almost as strongly marked as in the severest Inflammation; but the two conditions are at once distinguished by the relative proportions of solid matter in the blood, as indicated by the size of the coagulum. For in Chlorosis the coagulum is very small, in consequence of the reduced proportion of corpuscles, and is almost invariably found floating in the serum; whilst in the ordinary Inflammatory condition it is of full size, frequently adhering to the side of the vessel. The colourless clots which are not unfrequently found in the Heart after death, have the same composition as the Buffy Coat; being made-up of a network of fibres entangling in its meshes a large amount of Colourless corpuscles (Fig. 132).

Fig. 132.*

534. We have now to notice the principal differences which the Blood exhibits in different parts of the circulating apparatus; and the first and most important of these differences is that which is presented by *Arterial* and *Venous* blood. In passing through the capillaries of the System, Arterial blood loses its bright florid hue, and assumes the dark purple tint which distinguishes

* Colourless Corpuscles and fibres of Fibrin in a pale clot.

ordinary Venous blood; and the converse change takes-place in the capillaries of the Lungs, the original florid hue being recovered. Now it is certain that the blood, in its change from the arterial to the venous condition, loses oxygen, and becomes charged with an increased amount of carbonic acid, although its precise mode of combination is not known; on the other hand, in its return from the venous to the arterial state, the blood gives-off this additional charge of carbonic acid, and imbibes oxygen (§ 536). These changes of colour, under similar conditions, take-place out of the body, as well as in it. Thus, if venous blood be exposed for a short time to the air, its *surface* becomes florid; and the non-extension of this change to the interior of the mass is evidently due to the impossibility of bringing air into relation with every particle of the blood, in the manner which the Lungs are so admirably contrived to effect. If Venous blood be exposed to pure Oxygen, the change of colour will take-place still more speedily; and it is not prevented by the interposition of a thick animal membrane, such as a bladder, between the blood and the gas. On the other hand, if Arterial blood be exposed to Carbonic acid, it loses its brilliant hue, and is rendered as dark as venous blood; or even darker, if exposed very completely to its influence. The simple removal of this carbonic acid is not sufficient to restore the original colour; for this removal may be effected by hydrogen, which has the power of dissolving-out (so to speak) the carbonic acid diffused through the blood, without the restoration of the arterial hue, which does not return unless oxygen be present, or saline matter be added to the blood.

535. Now it is certain that these changes are in great part due to alterations in the chemical condition of the colouring matters of the Red Corpuscles; for a solution of Hæmato-crystallin, in which no corpuscles are present, and which is coloured by the presence of Hæmatin, is brightened by oxygen and darkened by carbonic acid. And the recent researches of Prof. Stokes on the optical characters of the *Cruorin* or colouring matter of fresh blood, have shown that it may exist in two states,—the *red*, and the *purple;*—and that whilst the purple can be converted into the red by oxygenation, the red can be reconverted into the purple not merely by treating it with carbonic acid, but by any chemical agency which deprives it of oxygen.—There is reason to believe, however, that the changes in the colour of the blood are due not merely to the oxygenation and the reduction of the Cruorin, but in part also to changes in the *form* of the Red Corpuscles, which may be effected without the production of any chemical changes in their composition. For blood may be brightened by the addition of saline solutions, and darkened by dilution with water; and it appears that the effect of oxygen, like that of saline solutions, is to contract the corpuscles and to condense their walls, so as, by alter-

ing their mode of reflecting light, to make them appear bright-red; whilst carbonic acid, like water, occasions a dilatation and attenuation of the corpuscles, of which the optical effect is to darken their hue.

536. The determination of the relative amounts of Oxygen, Nitrogen, and Carbonic Acid which are contained in Arterial and Venous blood respectively, is a matter of great difficulty; since it is certain that the greater proportion of the first and last of these gases is not merely absorbed (in which case it might be removed by keeping the Blood in a vacuum for a sufficient length of time), but is chemically united with some of the constituents of the blood. As already stated, there is reason to regard the Hæmatin of the Red corpuscles as the chief carrier of Oxygen; and the Phosphate of soda dissolved in the Serum as the principal vehicle for the Carbonic acid. There is no question that a very marked difference exists between the absolute and relative proportions of Oxygen and Carbonic acid in Arterial and Venous blood respectively; and it also appears that a great difference in this respect exists between the samples of blood drawn from different Veins, according as these have returned from Muscles *at rest* or from Muscles *in activity*, as is shown in the following Table:—

	Total Gases.	Oxygen.	Nitrogen.	Carb.Acid.
Arterial Blood	43·515	17·334	1·636	24·545
Blood returning from Muscles at rest	40·450	7·5	1·364	31·586
Blood returning from Muscles in Activity	37·069	1·265	0·923	34·881

Putting aside the trifling variation in the amount of Nitrogen as a fact of which no explanation can at present be given, we notice a marked diminution of Oxygen in ordinary Venous blood, but an almost complete disappearance of that gas in the Venous blood returned from Muscles in action. On the other hand, we notice that the increase in the volume of Carbonic acid which appears in ordinary Venous blood is only about 7-10ths of the volume of Oxygen which has disappeared; whilst its increase in the Venous blood returning from muscles in action is no more than about 5-8ths of the Oxygen which has disappeared. Hence it is obvious that the Oxygen supplied by the Blood which circulates through Muscles in action must enter into combination with other substances than Carbon; and it is probable that numerous processes of oxidation take-place in their substance, of which we encounter the final results in the Urinary secretion.—The only other characteristic difference between Arterial and Venous blood, consists in the larger quantity and higher elaboration of the fibrin

contained in the former, rendering its coagulum firmer and more tenacious: and there is evidence that this difference depends upon the oxygenating action to which the Venous blood is subjected in its passage through the capillaries of the lungs. Other occasional differences will be produced by the discharge of the contents of the Thoracic duct into the Venous system near the heart, and by an unusual transudation of the fluids of the blood during its circulation through the Secretory organs and the Tissues generally.

537. The blood of the *Mesenteric Vein*, if drawn whilst the process of Digestion is actively going-on, shows notable differences in composition from ordinary Venous blood. The whole proportion of solid constituents is diminished by the dilution it has sustained through the absorption of much additional fluid; and this diminution specially shows itself in the Red corpuscles and Fibrin, the relative proportion of Albuminous matter being augmented by the introduction of *Albuminose* (§ 473). The fibrin, when separated by stirring, shows a marked deficiency in tenacity, and liquefies again in the course of a few hours. The quantity of Extractive is usually increased; and in this part of the blood there may be detected sugar, dextrin, gelatin, and other soluble matters taken directly into the blood-circulation (§ 492). Towards the conclusion of the digestive process, however, the blood of the Mesenteric veins comes more nearly to present the characters of ordinary Venous blood; and in an animal that has been subjected to long abstinence, it does not exhibit any difference whatever.—The blood of the *Splenic Vein* also exhibits peculiarities which differ according to the stage of the digestive operation and the general condition of the nutritive functions. There is usually a marked diminution of Red corpuscles, with an increase of Fibrin, Albumen and Colourless corpuscles; the total quantity of solid matter, however, being diminished. The increase of Albumen seems to be the greatest at an interval of some hours after feeding; as if the organ were then giving back, in a state of greater preparedness, the material which has temporarily augmented its bulk.—In regard to the peculiar characters of the blood of the *Hepatic Vein*, there is considerable diversity of statement among the observers who have examined it. The most constant fact is the presence of *Sugar*, formed by the conversion of the Hepatin generated in the Liver (§ 174); and this continues to show itself in the blood of the Ascending Cava, of the Right side of the Heart, and of the Pulmonary artery; but unless present in excessive amount, it is usually eliminated completely during the passage of the blood through the Capillaries of the Lungs, so as not to show itself in the blood of the Pulmonary vein, or in that of the Arterial system generally. There is reason to believe that Fat also may be generated in the Liver, at the expense either of Amylaceous and Saccharine compounds, or of

Albuminous substances; the blood of the Hepatic Vein often containing a considerably larger proportion of it than is found in the blood of the Vena Portæ. Here, too, the proportion of Colourless to Red corpuscles seems to exhibit a decided increase.—The composition of the blood of the *Renal Vein*, when the secretion of Urine is actively going-on, has been found to present the differences which might be expected from that of the Renal Artery; the proportion of Water, of Salines, and of Urea being perceptibly diminished.

CHAPTER VII.

OF THE CIRCULATION OF THE BLOOD.

1. *Nature and Objects of the Circulation of Nutrient Fluid.*

538. The Nutritive Fluid—the elements of which are thus partly taken-up and prepared by the Absorbent system, but in great part also imbibed through the Blood-vessels distributed upon the walls of the digestive cavity, and assimilated by the Liver (§ 493) and the Vascular Glands (§§ 504-14),—is carried into the various parts of the system by the act of Circulation. This movement answers various purposes. It furnishes all the tissues which are to derive nutriment from the Blood, with a constantly-renewed supply of the materials which they severally require; and in this manner it is subservient to the growth, not only of those tissues which form part of the solid structure of the body, but also of those various cells covering its free surfaces, which are continually being cast-off and renewed, and which, in the course of their development, separate from the blood the products that are to perform ulterior purposes in the economy, or are to be removed as altogether effete. Thus the Circulation is subservient to the functions of Nutrition and Secretion. In the exercise of these functions, different materials are drawn from the Blood by the several tissues it supplies; so that various portions of the blood, when returning from the several organs through which they have been transmitted, have undergone very different changes by the nutritive and secreting processes, according to the function of the organs which they have supplied. Hence if the same portion of the circulating fluid were constantly being transmitted to each organ and returned from it, its composition would speedily undergo a change that would render it no longer fit for its purposes. By the union of the different local circulations, however, into one general circulation, this change is prevented, and the whole mass of the blood is maintained in its normal or regular condition; for since its composition is such as to supply all parts

of the body in a state of health, with the proportions of nutritive material which they respectively need, and since the returning currents are all mingled-together in the vessels before being again distributed to the system, each part supplies what the other has been deprived-of; and thus the normal proportion of ingredients in the whole mass of the blood is constantly kept-up, whilst in each of its separate streams it is undergoing an alteration of a different kind.

539. But these processes alone might be carried-on by the aid of a much less rapid Circulation than that which exists in Man and the higher animals. We do, in fact, occasionally meet with examples in which they continue for some time, under an almost total stagnation of the current. There are others, however, which require a much more rapid and uninterrupted movement of the circulating fluid. We have already seen that, for the *action* of the Nervous and Muscular tissues, Oxygen is necessary; and the amount of that gas contained in the blood circulating through these tissues would be very speedily exhausted if it were not continually renewed; whilst the Carbonic acid which is formed at the expense of that oxygen, would speedily accumulate to an injurious degree if it were not carried-off as fast as it is produced. Hence we find that, in all Animals, the maintenance of the Respiration, by carrying Oxygen from the respiratory surface into the different parts of the system, and by conveying-back Carbonic acid to be thrown-off at the Respiratory surface, is one of the great purposes of the Circulation of the blood; and its extreme importance is shown by the very speedy check which the interruption of this function produces in the movement of the blood in warm-blooded animals. Thus in a Bird or Mammal completely cut-off from Oxygen, the circulation in the lungs will come to a stop, and its stoppage will necessarily extend itself over the whole body, in little more than three minutes. We find, then, that the rate of the Circulation in different animals bears a relation to the energy of their Respiration; and this energy is closely connected with the general activity of their functions, but particularly with that of the Nervous and Muscular systems, which are most dependent for the exercise of their powers upon a continually-renewed supply of oxygen, and upon the unceasing removal of the carbonic acid which is generated in their substance.

2. *Different forms of the Circulating Apparatus.*

540. It is desirable that the Circulating apparatus should be first studied in its very simplest form,—that which it possesses in Plants and in the lowest tribes of Animals; as in this way alone can the forces which are concerned in the movement of the fluid be rightly appreciated. In the lowest Plants, such as Sea-Weeds,

however great the size they may attain, there is no transmission of nutritive fluid from one part to another; since every part of the surface can *absorb* for itself and for the subjacent structure, and every part of the interior can *assimilate* for itself. But in proportion as an axis of growth is developed, and the power of absorption is limited to the organs connected with one extremity of that axis (the roots), and that of assimilation to organs connected with the other extremity (the leaves), do we find a definite provision for the transmission of fluid from one part of the fabric to another.

541. The 'ascending sap' of a Tree consists principally of water, which is imbibed together with various substances held in solution by it, through the delicate tissue at the soft extremities of the root-fibres or 'spongioles.' The power of forcing upwards a column of sap, which exists in these bodies, and which seems due to Endosmose (§ 491), is shown by very simple experiments. If the stem of a Vine, or of any tree in which the sap rises rapidly, be cut-across when in full leaf, the sap continues to flow from the lower extremity; and this with such force as to distend with violence, or even to burst, a bladder tied firmly over the cut surface. If, instead of a bladder, a bent tube be attached to this, and mercury be poured into it so as to indicate the pressure exerted, it is found that the rise of the sap takes-place with a force equal to the pressure of from one to three atmospheres (from 15 to 45lbs. upon the square inch)—or even more. Thus the ascent of the sap is partly due to a powerful *vis a tergo*, or impelling influence, derived from the point at which the absorption takes-place.

542. But, on the other hand, if the upper part of the stem be placed with its cut-surface in water, a continued absorption of that fluid will take-place, as is evinced by the withdrawal of the water from the vessel; the fluid which is thus taken-up, however, is not retained within the stem and branches, but is carried into the leaves, and is thence dissipated by exhalation. It is obvious, then, that the *vis a tergo* is not the sole cause of the ascent of the sap; but that a *vis a fronte* also exists, by which the fluid is drawn towards the parts in which it is to be employed. This is further made apparent by a few simple experiments. If a branch, when thus actively absorbing fluid, be carried into a dark room, the absorption and ascent of fluid immediately cease almost completely, but are renewed again so soon as the leaves are again exposed to light. Now we know from other experiments, that light stimulates the exhaling process (§ 87), whilst darkness checks it; and the cessation of the demand in the leaves thus produces a cessation in the absorption at the lower extremity of the stem. And this is the case also in the natural condition of the plant; as is easily shown by immersing the roots in water, and observing the respective quantities which are

removed by absorption during sunshine, shade, and darkness. On the other hand, the movement of the sap may be excited, when it would not otherwise take-place, by the production of a demand at the extremities of the branches; thus if a branch of a vine growing in the open air be introduced into a hothouse, and be subjected to artificial heat during the winter, its buds will be developed, its leaves will expand, and these will draw fluid to themselves through the roots and stems, which are still inactive as regards the remainder of the tree. And the natural commencement of that movement of the ascending sap which takes place with the returning warmth of spring, has been experimentally shown to occur, in the first instance, not in the neighbourhood of the roots, but nearest the extremities of the branches; the exhalation of fluid from the expanding buds being the first process, and a demand for fluid being thus created, which is supplied by the flow that is thus excited in the lower part of the stem,—this, again, being supplied from the roots, which are thus caused to recommence their absorbent function.

543. Thus we see that in the 'ascending sap' the movement is entirely regulated by the demand for fluid occasioned by the actions of the leaves; even though it is in great part dependent on the *vis a tergo* which has its seat in the spongioles. Not even this force, however,—powerful as it has been shown to be,—can produce the continuance of the upward flow, when the exhalation from the leaves is checked by darkness, and when the demand occasioned by the action of these organs is consequently suspended.

544. The 'descending' or 'elaborated' sap is more comparable to the blood of animals; having undergone a preparation or elaboration in the leaves, which adapts it to the nutrition and extension of the structure, and to the formation of the various secretions of the plant. A great part of the fluid of the ascending sap has been lost by exhalation: and the remainder, thus concentrated, receives a large additional supply of solid matter through the agency of the green cells of the leafy parts, which take-in carbon from the atmosphere (§ 83); so that it now includes a considerable amount of plasmatic material in a state of preparation for being converted into solid tissue, as well as other compounds. This 'elaborated sap' seems to be conveyed into the various portions of the system by transmission from one cell to another, especially in the 'cambium-layer' between the bark and the wood, which is the seat of the most active formative changes.

545. In all the higher members of the Animal kingdom, we find a distinct *circulation* of blood, maintained by means of a central propelling cavity or Heart, from which pass forth vessels termed Arteries, which convey the blood to the various organs of

the body, and to which the blood is brought back by another set of vessels, the Veins; the communication between the two being established by the network of *Capillaries* in which the Arteries terminate and from which the Veins originate. In the lowest Animals, however, no circulation is required, for the same reason that no sap-vessels exist in the lowest Plants;—namely, because every part absorbs and assimilates nutritious fluid for itself, so that it does not require a supply from vessels. In the *Cestoid Entozoa* there is not even a gastric cavity or intestinal tube; for these parasites are supported by the juices of the animals they infest; and as the softness of their bodies fits them to imbibe these through their whole external surface, no more special organization seems to be necessary. And this is the condition of the early embryo even of Man; which consists of an aggregation of cells, every one of which can absorb for itself the nutriment it requires from the fluid with which it is surrounded, and goes through all its functions independently of the rest.

546. The general fact is, however, that Animals possess a Digestive sac within which their food is reduced to a condition fit for absorption; and in the simpler *Zoophytes* and the *Trematode Entozoa*, we find the whole substance of the body nourished by direct absorption from the *internal* surface which forms the lining of that cavity. In the same manner, the Aëration of the animal fluids,—or the exposure of them to the air contained in water, by which they may part with carbonic acid and imbibe oxygen,—is provided-for, not by any special respiratory organs, but by the contact of water with every portion of the soft external and internal surfaces. Further, as the substance of their body is nearly of the same kind in every part, they do not require the continual interchange of the fluid distributed to its several portions. Hence no circulation is necessary in these simple animals, either for the nutrition of their tissues, or for the aëration of the fluids. Sometimes, however, the gastric cavity is extended into canals, which convey the fluid portion of its contents to parts of the surface specially adapted by its ciliary currents to subject them to the aërating action of the surrounding medium.

547. The next step in the development of the Circulating apparatus consists in the separation of the outer walls of the digestive sac from the general substance of the body, by the interposition of a cavity termed the 'general cavity of the body,' or 'perivisceral cavity.' Into this the nutritive fluid transudes from the digestive sac; and from this it is absorbed by the surrounding tissues. The fluid of this cavity is generally corpusculated; its corpuscles resembling the chyle- and lymph-corpuscles of higher animals. Not unfrequently the perivisceral cavity is extended into prolongations, which convey its fluid to special organs of aëration.—This type presents itself in the higher Zoophytes and Echinoderms, and in the lowest Annelids and Mollusks.

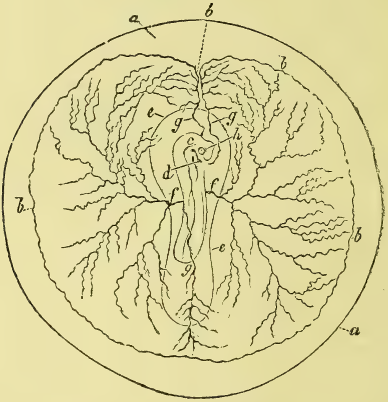
548. Proceeding a little higher, we find the first appearance of proper vessels in the *Echinodermata* (Star-fish and Sea-urchin tribe). What is their precise function, however, has not yet been fully ascertained. The general nutrition of the fabric seems to be provided-for in great part by the fluid of the perivisceral cavity; and this is carried by special extensions of the cavity into respiratory organs developed from the outer surface of the body. Moreover we still find in this class (as the Author has ascertained by recent researches) a diffusion of nutrient material by means of a sarcodic movement like that of the Rhizopods (§ 199). But there is also a system of distinct vessels, most highly developed in *Holothuria*, which seem, like the mesenteric veins of higher animals, to take-up the nutritive fluid from the walls of the digestive cavity on which they are spread-out, and then unite into trunks by which the fluid is conveyed to the more distant parts of the structure; these trunks again subdivide, and form a network of capillary vessels, which are dispersed through the several parts of the fabric; some of them being very abundantly distributed upon a portion of the surface which is particularly destined to perform the respiratory function. Through these capillary vessels the fluid seems to move without any distinct *vis a tergo* derived from the contractile power of a propelling organ.

549. Now this seems very much the condition of the Human embryo, at the time when vessels are first developed in its substance. These vessels are formed by the coalescence of cells (§ 323); and from the contents of these cells, which have been imbibed from the yolk, the first blood seems to be derived. The first formation of blood-vessels takes place, not in that part of the embryonic structure which is to be developed into the perfect animal, but in a membranous expansion from it which surrounds the yolk, and which answers the purpose of a temporary stomach. A capillary network is formed in a limited portion of this membrane, termed the *vascular area* (Fig. 133); and this does not originate in the branching of larger trunks, these trunks being subsequently formed by the reunion of the capillaries. The first movement of the blood is *towards* the central spot in which the organs of the permanent structure are being evolved; and since it takes-place before the incipient heart has acquired any muscularity, it would seem to be quite independent of any contractile force exerted by that organ. Here, too, we perceive that the circulation is essentially *capillary*, and that it is sustained by forces very different from those of which the action is most evident to us in the higher animals.

550. As we ascend the animal scale, however, we find that provision is made for a more regular and vigorous Circulation of the Blood, than that which exists in the lowest classes. Even in the class of *Echinodermata*, a portion of the principal vessel is

peculiarly endowed with contractile power; and this may be seen in constant pulsation, like the heart of the higher animals, alternately contracting to propel the fluid it contains through the vessels that issue from it, and then dilating to receive a fresh supply

Fig. 133.*



from the vessels that pour their contents into it. It seems quite certain, however, from the extent of the vascular system of these animals, that the influence of such a pulsatile cavity must be quite insufficient to keep-up the movement of blood through it. A similar provision is observable in the lower tribes of *Worms*, in which this contractile vessel lies along the back; propelling the blood forwards by a sort of peristaltic movement, through trunks which pass-out at its anterior termination, and receiving it again after it has circulated through the system, by vessels which enter at its posterior extremity. It is a remarkable peculiarity of many of the Marine Worms, that the *respiratory* fluid is distinct from the *nutritive* fluid. The former is red, but without corpuscles, and circulates in a regular system of vessels with definite walls. The latter is colourless and corpusculated; and moves in the perivisceral cavity and in prolongations from it. In many of the higher Annelids, such as the *Terebella* (Fig. 146), there is

* Vascular area of Fowl's egg, at the beginning of the third day of incubation:—*a*, *a*, yolk; *b*, *b*, *b*, *b*, venous sinus bounding the area; *c*, aorta; *d*, punctum saliens, or incipient heart; *e*, *e*, area pellucida; *f*, *f*, arteries of the vascular area; *g*, *g*, veins; *h*, eye.

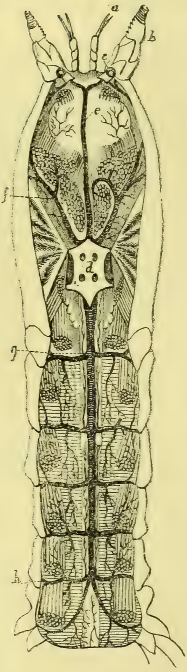
distinct provision for the aëration of both these fluids; the red blood (?) being transmitted through regular gills (*k*, *k*), and the white through the numerous tentacular filaments (*b*, *b*). In others, however, the red fluid alone is transmitted through any organs that can be regarded as specially respiratory; whilst in the inferior forms of the class, the red fluid and its system of vessels are altogether wanting, and there is only the colourless corpusculated fluid to be submitted to aëration.

551. In the *Myriapoda* or Centipede tribe, and in *Insects*, we find this dorsal vessel divided by transverse partitions containing valves, into separate cavities which answer to the different segments of the body. Each of these is, to a certain extent, the heart of its own segment, receiving and propelling blood by trunks which open into it; but they all participate in the more general circulation just described, a large portion of the blood being poured into the hindermost segment, transmitted forwards from cavity to cavity through the valves which separate them, and at last propelled through trunks that issue from the most anterior segment. In some instances we find that two or three of these trunks on either side pass round the œsophagus, and reunite below it, so as to enclose it in a sort of collar; and they form a main trunk by this union, which runs backwards along the under surface of the body, and which distributes the blood to its different organs by lateral branches. These subdivide into a capillary network; and the returning vessels which originate in this network, pour the blood which has circulated through it into the posterior cavity of the dorsal vessel.

552. The same general plan prevails among the lower *Crustacea;* but in the higher types of this class, such as the Crab and Lobster, we find a distinct heart (Fig. 134, *d*), consisting of a short fleshy sac, possessed of considerable muscular power, and concentrating in itself the propulsive force which is diffused in the lower tribes through a large part or the whole length of the dorsal trunk. From the anterior part of this sac there is given off a large *ophthalmic* trunk, *e*, which passes forwards and soon subdivides into branches for the supply of the eyes and neighbouring organs, and also a pair of *antennary* arteries, *f*; whilst from its posterior extremity is given off the superior abdominal or *caudal* artery, *g*, *h*, from which successive pairs of branches are sent-forth laterally to the segments of the abdomen. Besides these, a pair of large *hepatic* arteries are given off from the sides of the heart, to be exclusively distributed to the liver; whilst beneath the caudal artery a large *sternal* trunk originates, which supplies the thoracic members and the under side of the body generally. The blood distributed by these vessels does not remain confined in distinct tubes, but escapes from their terminations among the *lacunæ* of the tissues; and from these it appears to be collected by two sets

of large venous sinuses, of which one, lying immediately beneath the shell of the back, and covering the heart and dorsal arteries, carries it at once back to the heart, whilst the other, lying on the under side of the body, distributes the blood it has received to the gills, after passing through which (§ 658) it is returned in an aërated condition to the heart by the branchio-cardiac canals (Fig. 147, *e*). Hence in that central organ, the venous blood received from one portion of the body is mingled with the aërated blood returned from the respiratory apparatus; and the fluid propelled through the systemic arteries is hence of a mixed character,—as we shall see to be the case in Reptiles (§ 561).

Fig. 134.*



553. In most of these animals there are distinct organs of Respiration, confined to some one part of the body; and we often find that the vessels which convey blood to them are furnished with distinct contractile portions, like so many supplementary hearts, for the purpose of propelling the blood through them more energetically. In proportion as we ascend the series of Articulated animals, do we find, for the most part, a more vigorous and regular circulation, both for the nutrition of the system, and for the transmission of the blood through respiratory organs; but there is an exception in the case of *Insects*, which deserves special notice. In this class the circulation is much less vigorous than it is in other Articulated animals of similar complexity of structure; though it might have been anticipated that the extraordinary activity of their movements would necessitate a corresponding rapidity in the circulating current, especially for the purpose of conveying an extraordinary supply of oxygen to the nervous and muscular systems. But this is provided-for in another way; the

* Circulating apparatus of Lobster, as seen from above:—*a*, *b*, antennæ; *c*, eyes; *d*, heart; *e*, ophthalmic artery; *f*, antennary arteries; *g*, *h*, caudal artery.

air being conveyed to these tissues, not through the blood, but by direct transmission through the minute ramifications of the air tubes or tracheæ, which penetrate the very smallest organs of the body (§ 659).

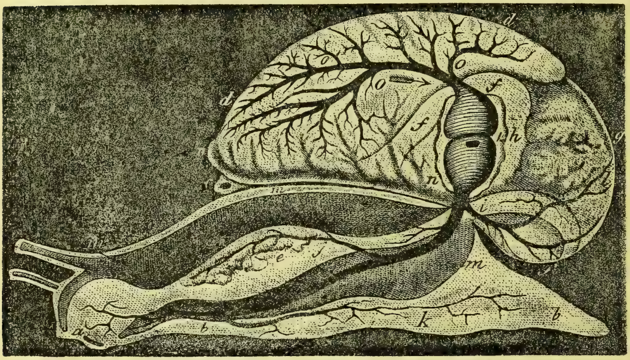
554. The condition of the Circulating apparatus in the Embryo of higher animals, at a period a little advanced beyond that already alluded-to, presents a striking analogy with that last described; for the heart, at the time of its first formation, seems like a mere dilatation of the principal vascular trunk, having thickened walls, in which, after a time, muscular fibre begins to be developed, and the contractile power manifests itself. The pulsation of this heart, however, does not seem to extend its influence immediately through the vascular area; the capillary circulation in which remains for some time in great degree independent of it. There is no resemblance in *form*, however, between the dorsal vessel of Insects, and the incipient heart of the higher animals; since the latter is never much prolonged, and speedily becomes doubled (as it were) upon itself; and its first division into distinct cavities is merely for the purpose of separating its *receiving* portion, or *auricle*, from its *propelling* portion, or *ventricle*. But the general *condition* of the Circulating system is much the same in the two cases; and it is further alike in this,—that it is not always easy to show that the vessels have distinct walls, as they frequently seem like mere channels excavated in the tissues.

555. We may next turn our attention briefly to the condition of the Circulating apparatus in the *Molluscous* classes, which has lately been found to present some very peculiar characters. In these it would seem as if the moving power were more concentrated in the heart than in the preceding; for this organ seems no longer like a mere dilatation of the vascular trunk, but is a distinct sac with muscular walls (Fig. 135, *h*), usually having at least two cavities, an auricle and a ventricle. The ordinary course of the Circulation is the following. The blood, expelled from the ventricle of the heart, passes along the main systemic artery or aorta, *i*, which distributes it to the body at large. It is then collected again by venous sinuses, *n*, *n*, and transmitted to the respiratory organs; in which it is exposed, either to the air contained in the surrounding water, or (in the terrestrial Mollusks) more directly to the atmosphere; and from these it is returned to the heart by the venous trunk, *o*, *o*, conveying aërated blood, to be again transmitted to the system generally.—Thus we see that the heart of these animals receives and impels *aërated* blood; and that its office is, to send that blood to the capillaries of the general system. Hence it may be called a *systemic* heart.

556. The blood, in the first part of its course, passes through distinct vessels: it has been lately shown, however, that in the Mollusks in general, the blood which has passed through the

systemic capillaries, and is on its way to the respiratory organs, is no longer thus confined, but that it meanders through passages or *lacunæ* which are channelled-out in the tissues, wherein they even communicate freely with the perivisceral cavity (Fig. 135, *m*, *m*), so that the exterior of the viscera is bathed by the

Fig. 135.*



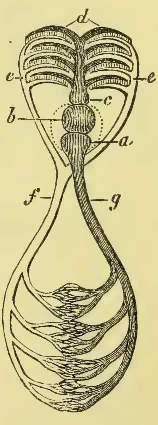
circulating fluid. It is perhaps in this part of its course that it most readily takes-up the fresh nutrient materials which have been prepared in the alimentary canal, and which would under such circumstances find their way with comparative facility from the inner surface of its walls to the outer.—After being thus diffused, in its venous or carbonized state, through the substance of the tissues and through the perivisceral cavity, it is again collected into distinct trunks; and these convey it to the respiratory organs.—Now although it cannot be doubted that the impelling power of the heart is the chief cause of the movement of the blood through the systemic vessels, yet it would seem impossible to suppose that this power can be exerted over the unrestrained currents in which it is diffused through the body, after passing through the systemic capillaries; and it can scarcely be doubted that its passage through the capillaries of the respiratory organs is due to some power developed in themselves.

* Anatomy of Snail:—*a*, mouth; *b*, *b*, foot; *c*, anus: *d*, *d*, pulmonary sac; *e*, stomach, covered above by salivary glands; *f*, *f*, intestine; *g*, liver; *h*, heart; *i*, aortic trunk; *j*, gastric artery; *k*, artery of foot; *l*, hepatic artery; *m*, *m*, perivisceral cavity serving as venous sinus; *n*, *n*, irregular canal communicating with abdominal cavity and conveying blood to pulmonary sac; *o*, *o*, pulmonary vein.

557. There is a very curious phenomenon to be observed in the circulation of some of the lowest Mollusks belonging to the class *Tunicata* (Fig. 144, *e*); namely, the continual *reversal* of the course of the current. The heart in these animals is much less perfectly formed than in the higher tribes; and seems more like the mere contractile dilatation of the principal trunk which is the sole representative of that organ in the Echinodermata. The circulating fluid is sometimes transmitted first to the system; after being distributed to its different parts by the ramifications of the main artery, it meanders through the channels excavated in the tissues; and it then flows towards the respiratory surface, after passing over which, it returns to the heart. But after a certain duration of its flow in this direction, the current stops, and then recommences in the contrary direction,—proceeding first to the respiratory organs, and then to the system in general. It would seem as if in this, one of the lowest forms of animals possessing a distinct Circulation, the central power were not yet sufficiently strong to determine the course which the fluid is to take, so that it undergoes continual vacillations.

558. We have now to consider the chief forms in which the Circulating apparatus presents itself in the Vertebrated classes; and first in that of *Fishes* (Fig. 136). We have here, as in Mollusks, a heart with two cavities, an auricle *a*, and a ventricle *b*; this heart, however, is not placed at the commencement of the systemic circulation, but at the origin of the respiratory vessels. The blood which it receives and propels is venous or carbonized; this is transmitted along a main trunk *c*, which speedily subdivides into lateral branches or arches *d*, and these distribute it to the fringes of gills that hang on the sides of the neck. By the action of the water on the gills, the blood is aërated in its passage through them; and it is then collected by a series of converging vessels *e*, *e*, which reunite to form the great systemic artery or aorta *f*. By the ramifications of this artery, the blood, now aërated, is distributed through the system, and affords the

Fig. 136.*



* Diagram of the Circulating Apparatus of *Fishes*:—*a*, the auricle; *b*, the ventricle; *c*, the trunk supplying the branchial arteries *d*; the aërated blood returning from the gills is conveyed by *e*, *e*, the branchial veins, to *f*, the aorta, which distributes it to the system; thence it is collected, and returned to the auricle, by the veins which unite in the vena cava *g*.

requisite nourishment and stimulation to its tissues. Returning from the systemic capillaries in a venous state, the blood of the head and anterior portion of the body finds its way at once into the great systemic vein, or vena cava *g*, by which it is conveyed back to the auricle of the heart; but that which has traversed the capillaries of the posterior part of the body and of the abdominal viscera, is conveyed by a distinct system of veins to the Liver and the Kidneys. In these organs, the veins again subdivide into a network of capillaries, which is distributed through the secreting structure, and which affords to the secreting cells the materials of their development. This is termed the *portal* system of vessels. From the capillaries of the liver and kidneys, the blood is finally collected by the hepatic and renal veins, which convey it into the vena cava; where it is mingled with the blood that has not passed through those organs, and is conveyed with it to the heart.

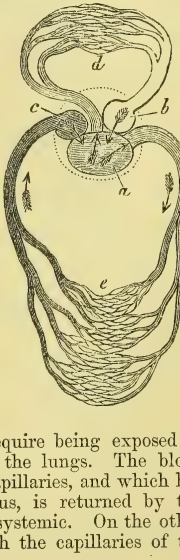
559. The heart of Fishes, then, belongs to the *respiratory* circulation. It propels venous blood to the capillaries of the gills, in which it is aërated; returning from these, the aërated blood is transmitted through a second set of capillaries, those of the system, in which it again becomes venous; whilst a portion of this blood is made to traverse a third set of capillaries, those of the liver and kidneys, before it is again subjected to the propelling power of the heart. Now as the heart, instead of being stronger than it is in animals with the complete double circulation presently to be described (§ 564),—in which the greater part of the blood propelled by the central organ only traverses one set of capillaries, and never more than two,—is much weaker in proportion, it is evident that here, too, a supplementary power must exist, by which the flow of blood through the capillaries is aided, and on which, indeed, the portal circulation must greatly depend.

560. An extremely interesting aspect of the circulating apparatus is presented by the *Amphioxus* or Lancelot; an animal which possesses the general form of a Fish, and which can scarcely be referred to any other group; but in which the characters of the Vertebrated series are degraded (as it were) to the level of the lower Molluscous and Vermiform classes. The blood, which is white, moves through distinct vessels, but there is no proper heart; and the vascular trunks present several dilatations in different parts, which have muscular walls and show contractile power. Thus the circulation is carried-on, not through the agency of a central impelling organ, as in other Fishes; but by a power which is scattered or diffused through various parts of the system of blood-vessels, as in the lower Invertebrata.— The respiratory apparatus, also, is formed upon a type much lower than that of Fishes; for it consists simply of a dilatation of the first part of the alimentary canal, or pharynx, upon the walls of

which the blood is distributed in divided streams, its cavity being filled with water, which serves to aërate the blood. This is precisely the type on which the respiration is effected in those lowest Mollusks, of which mention has just been made as exhibiting alternations in the direction of the circulating current (§ 557). In other respects, however, the arrangement of the vascular system in this extraordinary animal corresponds with that which obtains in Fishes.

561. It is requisite that, in the class of Fishes, the *whole* of the venous blood returned from the system should pass through the respiratory organs, before being again transmitted to the body; since the aërating action of the small quantity of air diffused through the water, would otherwise be insufficient for its renovation. But in *Reptiles*, all of which breathe air during their adult condition, the case is very different; for if the whole current of their blood were exposed to the atmosphere, before being again sent to the body, the quantity of oxygen conveyed into the tissues would be too great, and would have an overstimulating effect. The plan of Circulation is, therefore, differently arranged in Reptiles (Fig. 137). We find the heart to consist of three cavities; two auricles, and one ventricle. From the ventricle *a* issues a single trunk, which speedily subdivides; some of its branches *d* proceeding to the lungs, and others *e* to the body. The blood which is transmitted through this trunk, is of a mixed character, as we shall presently see; being neither fully aërated, nor yet highly carbonized. It contains sufficient oxygen to stimulate the nervous and muscular systems of these comparatively inert animals; whilst it also contains enough carbonic acid to require being exposed to the atmosphere through the medium of the lungs. The blood which has passed through the systemic capillaries, and which has been thereby rendered completely venous, is returned by the vena cava to one of the auricles *c*,—the systemic. On the other hand, the blood which has passed through the capillaries of the

Fig. 137.*



* Diagram of the Circulation in *Reptiles:—a*, single ventricle, receiving aërated blood from *b*, the pulmonary auricle, and venous blood from *c*, the systemic auricle; and propelling part of this mixed fluid to the pulmonary capillaries, *d*, and part to the systemic capillaries, *e*.

lungs, and which has been thereby rendered completely arterial, is returned through the pulmonary vein to the other auricle *b*,—the pulmonary. Thus one of the auricles exclusively receives oxygenated, and the other carbonated blood; and as both pour their contents into the common ventricle, the blood which that cavity contains and propels is of a mixed character.

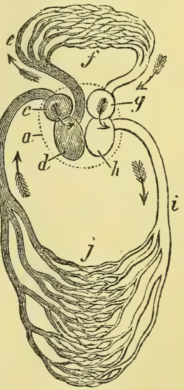
562. Various modifications of this form of Circulating apparatus exist in the different groups of Reptiles. In the lowest among them (the *Perennibranchiate Amphibia*), which breathe permanently by gills like Fishes, besides possessing imperfectly developed lungs, the apparatus exhibits a blending of both plans; for a small portion of the blood which is propelled by each contraction of the ventricle, passes directly to the lungs; the principal part of it being at once distributed to the gills, as in Fishes. After passing through these, it is transmitted to the general system; and on returning thence in a completely venous state, it is mingled with the blood which has been arterialized in the lungs. This latter, however, bears so small a proportion to the rest, that, if the aëration were not partly effected by the gills, it would be insufficient for the wants of the animal.—The tadpoles of the common Frog and Water-newt, as well as of other species which, like them, begin life in the general condition of Fish, present a similar condition at one period of their change. At first the whole aëration is effected by the means of gills, the lungs being in a rudimentary or undeveloped state; and the entire circulation is carried-on as in Fishes, the pulmonary vessels being scarcely traceable. As the lungs begin to be developed, however, a portion of the blood is sent to them; and at the same time communicating passages which previously existed between the vessels that convey blood to the gills and those that return it from them, are increased in size; so that a certain proportion of the blood is transmitted to the system, without having passed through the gills at all. By a further increase in the diameter of these, the whole current of blood takes this direction, the gills being no longer serviceable; and as, at the same time, the lungs are attaining their full development, the aëration which they effect in the blood transmitted to them becomes sufficient, and the whole circulation is thus permanently established on the Reptilian type.

563. Among the higher Reptiles, on the other hand, we find the Circulating apparatus presenting approaches to the form it possesses in Birds and Mammals. For the ventricle is divided, more or less completely, into two cavities, one of which propels aërated blood to the system, whilst the other transmits venous blood to the lungs. A certain amount of mixture of arterial and venous blood always takes-place, however, either in the heart itself, or in the vessels; so that the blood which the body receives

is never purely arterial. But this mixture is sometimes effected in such a manner that pure arterial blood is sent to the head and anterior extremities, though the remainder of the body receives a half-aërated fluid. This is accomplished in the Crocodile, by a provision very similar to that which exists in the fœtus of warm-blooded animals (CHAP. XII). The *portal* circulation in Reptiles is carried-on nearly upon the same plan as in Fishes. It receives the blood from the posterior extremities and from the tail, as well as from the abdominal viscera; and this blood is distributed by the portal capillaries, not only through the Liver, but also through the Kidneys, although the latter also receive arterial branches from the aorta. The fact that the kidneys are supplied from the general portal circulation in Fishes and Reptiles, has an important bearing on the difference which will be hereafter shown to exist in the arrangement of the vessels, between the kidneys of these animals and those of Birds and Mammals (§ 728).

564. In the warm-blooded division of the Vertebrated series, which includes the classes of *Birds* and *Mammals*, we find the whole circulation possessed of a greatly increased energy; but the distinguishing peculiarity of the apparatus in these animals, is that conformation of the heart and vessels which secures a *complete double circulation* of the blood; that is, which provides for the aëration of every particle of the venous blood that has returned from the system, before it is again sent into the tissues. The heart may be regarded as consisting of two distinct parts,—a *systemic* heart, like that of the Mollusks, forming its left side,—and a *respiratory* heart, like that of Fishes, constituting its right (Fig. 138). Each of these parts has a receiving cavity or auricle, and an impelling cavity or ventricle. The cavities of the two sides are completely separated from one another, in the adult state at least; though their walls are united, for economy of material.

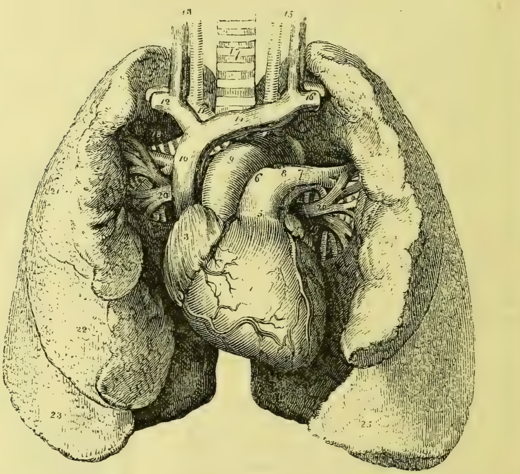
Fig. 138.*



* Diagram of the Circulating Apparatus in *Mammals* and *Birds:—a*, the heart, containing four cavities; *b*, vena cava, delivering venous blood into *c*, the right auricle; *d*, the right ventricle, propelling venous blood through *e*, the pulmonary artery, to *f*, the capillaries of the lungs; *g*, the left auricle, receiving the aërated blood from the pulmonary vein, and delivering it to the left ventricle *h*, which propels it through the aorta, *i*, to the systemic capillaries *j*, whence the venous blood is collected by the veins, and carried back to the heart through the vena cava *b*.

It is obvious that much is saved in this manner; since, as the contractions of the auricles and of the ventricles on the two sides occur simultaneously, the pressure of blood in the one is partly antagonized by that on the other, so far as it acts on the wall that is common to both. This antagonism is not complete, however, since the systemic ventricle contracts with far greater force than the pulmonary; and the wall between them must be capable of resisting the difference of pressure on its two sides thus occasioned.—The blood which is returned from the system, in a venous state, through the vena cava *b* to the right auricle *c*, and

Fig 139.*



* Anatomy of the Human Heart and Lungs:—1. the right ventricle; the vessels to the right of the figure are the middle coronary artery and veins; and those to its left, the anterior coronary artery and veins; 2. the left ventricle; 3. the right auricle; 4. the left auricle; 5. the pulmonary artery; 6. the right pulmonary artery; 7. the left pulmonary artery; 8. the remains of the ductus arteriosus; 9. the arch of the aorta; 10. the superior vena cava; 11. the right arteria innominata, and in front of it the vena innominata; 12. the right subclavian vein, and behind it its corresponding artery; 13. the right common carotid artery and vein; 14. the left vena innominata; 15. the left carotid artery and vein; 16. the left subclavian vein and artery; 17. the trachea; 18, the right bronchus; 19. the left bronchus; 20, 20. the pulmonary veins; 21. the superior lobe of the right lung; 22. its middle lobe; 23. its inferior lobe; 24. the superior lobe of the left lung; 25. its inferior lobe.

which is poured by it into the right ventricle *d*, is impelled by the latter through the pulmonary artery *e* to the capillaries of the lungs *f*, where it undergoes aëration. Returning thence, in an arterialized state, it is conveyed by the pulmonary vein into the left auricle *g*, and thence flows into the left ventricle *h*; by which it is propelled through the great systemic artery or aorta *i*, and through its ramifications to the general system.

565. The greater part of the blood which has been rendered venous by passing through the systemic capillaries *j*, is collected by the systemic veins *b*, and is returned directly to the heart through the vena cava. But a portion is still employed for that distinct circulation which is destined to supply the materials for the secreting action of the Liver. The blood that has traversed the capillaries of the walls of the alimentary canal, and of the other viscera concerned in digestion, is collected again by the converging veins into a large venous trunk, the *vena portæ*, by which it is distributed through the liver. This vessel, although formed by the convergence of veins, and conveying venous blood, has really the character of an artery in an equal degree; for it subdivides and ramifies after its entrance into the liver, so as to form a network of capillaries, from which the blood is again collected, and thence transmitted by the hepatic vein to the vena cava.—Thus that portion of the blood which supplies the liver with the materials of its secreting action, passes through two sets of capillaries, between the time of its leaving the heart and its return to it. The portal circulation in Birds, as in Reptiles and Fishes, receives the blood from the posterior part of the body and from the extremities; but the portal blood is only conveyed to the Liver, the Kidneys being supplied by the renal artery.

566. This perfect form of the Circulating apparatus is only attained, in the warm-blooded animal, after a series of transformations which strongly remind us of the permanent forms presented by the vascular system in Fishes and Reptiles. Thus in the embryo of the Chick at about the 60th hour, and in that of the Dog at about the 21st day, the curved and dilated tube of which the heart previously consisted (§ 554), is found to be distinctly divided into an auricle and a ventricle. From the latter originates the main arterial trunk, which divides into four pairs of lateral branches; and these pass round the pharynx, precisely in the position and direction of the arteries of the gills of Fishes. They do not, however, distribute the blood to gill-tufts, for none such are developed in the embryo of the warm-blooded animal; but they meet again below the pharynx, to form a trunk which supplies the general circulation.—Within a short period, however, the whole plan of the circulation undergoes a change. The auricle and the ventricle are each divided by a partition that is developed in the middle of the

heart; and thus the two auricles and the two ventricles are formed. Whilst this is going-on, a change takes-place also in the vessels that arise from the heart; for the arterial trunk that was previously single undergoes a division into two distinct tubes, one of which is connected with the left ventricle and becomes the aorta, whilst the other originates in the right ventricle and becomes the pulmonary artery. Of the four pairs of branchial arches, some are subsequently obliterated; whilst others undergo changes that end in their becoming the arch of the aorta, the right and left pulmonary arteries, and the right and left subclavians.

567. The muscular power of the Heart is much greater in the warm-blooded than in the cold-blooded Vertebrata, in proportion to the extent of the circulation which it is concerned in maintaining; and it is evidently destined to take a much larger share in the propulsion of the fluid, than it is in the lower tribes. Many Physiologists, indeed, are of opinion that the movement of the blood is *entirely* due to the action of the heart; and this view appears to be supported by the results of numerous experiments upon the circulation. But it is very difficult, if not impossible, to make experiments that shall be really satisfactory upon this point; and it appears safer to trust to the "experiments ready prepared for us by Nature," as Cuvier termed them,—namely, those lower forms of animated being in which various diversities of structure present themselves, and in which we can study the regular and undisturbed effects of these. Thus we have seen that in the lowest Animals which have no central impelling cavity, the movement of the nutritive fluid is entirely dependent upon the power that is diffused through the network of vessels in which it circulates. As we ascend the series, we find an organ of impulsion developed upon a certain part of the vascular system, whose object it is to give increased energy and regularity to the movement. And ascending still higher, we find the moving power gradually concentrated, as it were, in this organ; yet it is not altogether withdrawn from the capillary network, as we shall see from several facts to be presently adduced.—The particular actions of the Heart, the Arteries, the Capillaries, and the Veins, will now be considered in more detail.

3. *Action of the Heart.*

568. The Heart is a hollow muscle, endowed in an eminent degree with the property of *irritability;* by which is meant, the capability of being easily excited to movements of contraction alternating with relaxation (§ 341). The chief peculiarity in the Heart's action consists in its *rhythmical* character; which is well shown in the series of alternate contractions and relaxations

which follow a single slight irritation, when the organ has been removed from the body and has ceased to contract spontaneously. It is another remarkable feature in the Heart's action, that whilst the contraction of the two Ventricles is perfectly synchronous, as is that of the two Auricles, the contraction of the auricles is synchronous with the dilatation of the ventricles, and *vice versâ.* The regularity of this alternation, however, is somewhat disturbed when the irritability of the heart is becoming exhausted; and both sets of movements will continue when the auricle and ventricle have been separated from one another. Their regular succession, in the natural state, is doubtless in part due to the fact, that the transmission of blood from the auricle into the ventricle, by the contraction of the former, is the stimulus which most effectually excites the latter to contraction; whilst the ventricle is contracting, the auricle, now free to dilate, is distended by the flow of blood from the veins that open into it; and this flow stimulates it to renewed contraction, just at the time when the contraction of the ventricle has been completed, and *its* state of relaxation enables it to receive the blood poured-in through the orifice leading from the auricles.

569. In the living animal, the Auricular and Ventricular movements succeed one another with great regularity; and, when the circulation is proceeding with vigour, scarcely any appreciable pause can be discovered between the different acts. The contraction or *systole* of the Auricle occupies only about one-eighth of the entire period that intervenes between one pulsation and another, the diastole occupying the remaining seven-eighths. The systole and diastole of the Ventricles on the other hand, divide the entire period equally between them. The systole of the Ventricles occasions the propulsion of blood into the arterial system; and this action produces the *pulse*, as will be explained hereafter (§ 583). And it also corresponds with the *impulse* or stroke of the heart against the parietes of the chest. This impulse is produced, not, as some have supposed, by the swinging of the entire heart forwards; but by the peculiar mode in which the Ventricular systole takes-place. In the contraction of its walls every dimension is lessened, though *shortening* is the most perceptible change; but this does not occasion any elevation of the apex of the heart towards the base, its upward movement being neutralized by the descent of the whole heart occasioned by the elongation of the great vessels springing from its base. Owing to the peculiar spiral disposition of the fibres of the heart, its apex is not simply drawn upwards by their contraction, but it is made to describe a spiral movement, from right to left, and from behind forwards; and it is in this manner that it is caused to strike against the wall of the chest.

570. The systole of the Ventricles is immediately followed by

their diastole; but during the earlier part of this the Auricles are still dilating, the blood being poured into them by the great veins faster than it passes from them into the Ventricle. And thus the Ventricular diastole may be divided into two stages; the *first* seeming due to the simple elasticity of the walls of the Ventricles, whilst in the *second*, which is accompanied by the systole of the Auricles, the blood of the latter is forcibly propelled into them. When the circulation is being carried-on regularly, the blood is propelled into the Ventricles with sufficient force to dilate them strongly; so that the hand closed upon the heart is opened with violence. Even the auricles dilate with more force than it seems easy to account-for by the *vis a tergo* of the blood in the venous system, which is small compared with that which the fluid possesses in the arteries.

571. The natural movements of the Heart are accompanied by certain Sounds, which are heard when the ear is applied over the cardiac region; and an acquaintance with these sounds and with their causes is of much importance, since the alterations which they undergo in disease afford us some of our most accurate information in regard to the nature of the morbid affection. Concurrently with the *impulse* of the heart against the chest, a dull and prolonged *sound* is heard; this, which is termed the *first* sound, marks the Ventricular systole, and is synchronous with the Arterial pulse. The second sound, which is short and sharp, follows *immediately* upon the conclusion of the first; and it must therefore be produced during the first stage of the Ventricular diastole, before the systole of the Auricles has commenced. It is followed by a brief interval of repose, which occurs during the remainder of the Ventricular diastole and the Auricular systole; and this is succeeded by a recurrence of the first sound. If the whole period between two successive pulsations be divided into four parts, it is estimated by Volkmann that the two sounds together occupy two of these, and that the interval occupies the remainder.

572. Now in order to understand the causes of these Sounds, it is necessary to study the course of the blood through the heart a little more in detail. When the Ventricles, distended with blood, are contracting upon their contents, they eject them forcibly through the narrow orifices of the aorta and pulmonary artery; and the semilunar valves which guard these orifices, are thrown back against the walls of the arteries. The regurgitation of the blood into the auricles is prevented by the action of the mitral and tricuspid valves; but the flaps of these do not suddenly fall against each other when the blood first begins to press them together, being restrained by the *chordæ tendineæ*. The connection of these with the *carneæ columnæ*, which form part of the ventricular walls and contract simultaneously with them, appears

to have this use;—that the flaps of the valves, which are completely thrown-back during the preceding rush of blood from the auricles to the ventricles, may be drawn into a favourable position for the blood to get behind them and bring them together, so as completely to close the orifice. As soon as the ventricular diastole begins to take-place (even before the contraction of the auricles has commenced), there will be a tendency of the blood that has just been propelled into the aorta and pulmonary artery, to flow back to the heart; but this regurgitation is completely prevented by the semilunar valves of these orifices, which are immediately filled-out by the backward tendency of the blood, and which meet in such a manner as completely to close the orifices. This closure is much more sudden than that of the mitral and tricuspid valves, being altogether unrestrained.

573. Much discussion has taken place in regard to the cause of the *first* sound; which has been attributed to (1) the impulse of the heart against the parietes of the chest, (2) the contraction of the muscular walls of the ventricles, (3) the rush of blood through the narrowed orifices of the aorta and pulmonary artery, (4) the general molecular collision of the particles of blood against each other, and their friction against the walls of the ventricles, (5) the sudden collision of the stream of blood issuing from the ventricles with the column of blood at rest on the semilunar valves of the aorta and pulmonary artery, and (6) the tension of the valves of the auriculo-ventricular orifices. There is now, however, a general convergence towards the opinion, that the *last* is the *principal* (though perhaps not the sole) source of this sound. That the first sound is more prolonged than the second, is probably due to the fact that the tension of the auriculo-ventricular valves is not so sudden as that of the semilunar, as also to the larger size of the former.—The *third* of the above hypotheses has been specially based on the admitted fact that a *bruit*, which in slight cases seems only an intensification of the natural first sound, is produced by any obstruction to the free passage of blood through those orifices, as it is by narrowing the calibre of any large vessel by pressing the stethoscope upon it. But in the healthy heart it would seem as if the size of the different orifices were exactly proportioned to the current of blood that is to pass through them; so that we should no more expect its passage to give rise to a sound in the Heart than in the larger Blood-vessels. The first sound is modified also by disease of the Mitral and Tricuspid valves, which produces narrowing of their orifices, imperfect closure, rigidity of their substance, or roughness of their surface.

574. The *second* sound is unquestionably due to the sudden filling-out of the Semilunar valves with blood, at the moment when the Ventricular systole has ceased, and when the commencing diastole produces a tendency to the regurgitation of blood

from the Aorta and Pulmonary artery; a sort of *click* being produced by the sudden passage of the valves from a state of complete relaxation to one of complete tension. That this is the real cause, has now been fully demonstrated. If one of the valves be hooked-back against the side of the artery by the introduction of a curved needle, so that a reflux of blood is permitted, the sound is entirely suppressed. And if the complete closure of the valves be prevented by disease, so that their tension is diminished, and a certain amount of regurgitation takes-place, the second sound is no longer heard in its proper intensity; whilst, on the other hand, a *souffle*, sometimes prolonged through the whole interval of repose, indicates the reflux of the blood into the ventricles. When the Semilunar valves are thickened by morbid deposit, their surface roughened, and their opening narrowed, the *first* sound gives-place to a harsh and sharp bruit; and the *second* sound acquires the same character,—the backward as well as the forward flow of the blood being affected by this cause.

575. The ordinary movements of the heart do not produce any audible friction-sound between the two surfaces of the pericardium, that which covers the heart, and that which lines the pericardial sac. Their smooth surfaces are kept moist, in health, by the serous fluid constantly exhaling from them; and the intervention of this fluid allows of a certain 'play' of the heart within its investment. But if these surfaces become dry, as in the first stage of inflammation, a slight creaking is heard, accompanying *both* the ordinary sounds of the heart, and somewhat resembling the rustling of paper. And if they be roughened by the deposit of inflammatory exudations, this 'to and fro' sound becomes of a harsher character.

576. The walls of the left ventricle are considerably thicker than those of the right; and their contractile power is greater. This difference is obviously required by the difference in length between the systemic and the pulmonary vessels; the amount of force necessary to drive the blood through the latter, being far inferior to that which is requisite to propel it through the former. The average thickness of the walls of the *left* Ventricle is about $4\frac{1}{2}$ lines; being somewhat greater than this at the middle of the heart, and less at its apex. The average thickness of the walls of the *right* ventricle is not more than $1\frac{1}{2}$ line; being a little greater than this at the base, and less at the apex of the heart. The left auricle is somewhat thicker than the right.—The capacities of all the four cavities are nearly equal; each of them being stated to hold about *three ounces* of fluid when completely dilated. The Ventricles are, perhaps, a little larger than their respective Auricles; but there is no very positive difference in capacity between the Ventricles and Auricles of the two sides.

577. There is a difficulty, however, in understanding how the

Circulation can be maintained at the rate of which there is experimental evidence, unless a larger quantity of blood than three ounces be propelled from each Ventricle at every systole. The whole quantity of the blood being about one-eighth of the entire weight of the body (§ 524), it will amount to about 18 lbs. in an individual of 144 lbs. weight. Allowing 72 pulsations to a minute, 216 oz. (or 13 lbs. 8 oz.) of blood would pass through each ventricle of the heart in that time; consequently about eighty seconds would be required for the passage of the entire mass of the blood through the whole circle of its movement, if its rate be entirely determined by the impulses it receives from this central organ. Now it appears from various experiments, that the rate of circulation is much more rapid than this. For if a solution of any salt easily detectible in the blood be injected into one of the large veins near the heart, it may be traced in the arterial circulation in from 15 to 20 seconds afterwards; during which interval it must have traversed the whole pulmonary system of vessels, and passed through both sides of the heart. And if the salt be one which acts powerfully on the Heart itself,—as is the case with Nitrate of Baryta or Nitrate of Potass,—this action is manifested almost at the same moment with the appearance of the salt in the arteries of other parts; thus showing that it has been conveyed by the Coronary arteries into the capillaries of the cardiac tissue. The period required for the transmission of the saline substance from the veins of the upper part of the body to those of the lower,—which can scarcely be accomplished through any more direct channel than the current that returns to the heart, then passes through the lungs back to the heart again, and then flows through the systemic arteries and capillaries to the veins,—is accomplished in little more than 20 seconds, even in an animal so large as a Horse. Reasoning from data of this kind, Volkmann and Vierordt have concluded that the quantity of blood discharged from either ventricle of the Human heart at each systole is more than 6 oz.

578. The *force* with which the Heart propels the blood is such, that if a vertical pipe be inserted into the Carotid artery of a horse, the blood will sometimes rise in it to a height of 10 feet. From comparative experiments upon other animals, it has been estimated that the vigorous action of the heart in Man would sustain a column of blood in his aorta about $7\frac{1}{2}$ feet high; or, in other words, that the force with which the heart ordinarily propels the blood through the aorta, is equal to that which would be generated by the weight of a column of blood of the same size, and $7\frac{1}{2}$ feet high; which weight would be about $4\frac{1}{3}$ lbs. But the force which must be exerted by the heart to sustain such a column, may be shown, upon physical principles, to be as much greater than this, as the area of a plane passing through the base and apex of the left ventricle is greater than that of the transverse section of the

aorta; and since the proportion of these areæ is about 3 : 1, the real force of the heart may be stated at about 13 lbs.

579. The *number* of contractions of the Heart, in a given time, is liable to great variations within the limits of health, from several causes, the chief of which are diversities of Age and Sex, amount of Muscular exertion, the condition of the Mind, the state of the Digestive system, and the period of the Day.—The following are the points of greatest importance, in regard to the action of these several influences.

Age.—The pulse of the newly-born infant averages from 130 to 140 per minute; and this rate gradually diminishes, until, in adult age, the pulse averages from 70 to 80; and in the decline of life from 50 to 65.

Sex.—The pulse of the adult female exceeds that of the adult male in frequency, by about 10 or 12 beats in a minute; and it is also more liable to disturbance from other causes.

Muscular Exertion.—The effect of this in accelerating the pulse is well known; but as the amount of change depends upon the degree of exertion, no general statement can be made on the subject. The continued influence of a moderate degree of muscular exertion, is shown by the effect of *posture* upon the pulse. Thus the pulse is on the average from 7 to 10 beats faster (per minute) in the standing than in the sitting posture; and 4 or 5 beats faster in the sitting than in the recumbent posture. This amount of variation is temporarily increased by the muscular effort required for the *change* of posture; but this soon subsides into the continued rate which the permanent maintenance of the new posture involves. There are certain states of the system, in which the heart's action is increased to a most violent degree by a simple change of posture; and in which, therefore, it is necessary that even this slight movement should be made with gentleness and caution.

Mental Condition.—The action of the heart is peculiarly influenced, as every one is aware, by the excitement of the *emotions.* This is a fact to which, however familiar, the medical practitioner should constantly direct his attention. The trifling agitation occasioned by the entrance of the medical man will produce, in many patients, such an acceleration of the pulse, as would be very alarming, if its true cause were not known. And the real rate of the pulse cannot be ascertained until time has been permitted for the agitation to subside; which is favoured, also, by the influence of a gentle manner and tranquillizing conversation. The operation of the *intellectual* powers does not seem to affect the rate of the heart's movement in any other way, than by inducing a general state of feverishness, if it be too long or too energetically kept up.

State of the Digestive System.—The pulse is quickened during

the digestion of a meal; but no exact numerical statement can be made on this subject.

Period of the Day.—The frequency of the pulse appears to be somewhat greater in the morning than it is in the evening; and the temporary action of any of the preceding causes more quickly subsides in the evening than in the morning. The period of greatest depression seems to be usually between 3 and 5 A.M.

580. The movements of the Heart were formerly supposed to depend upon a constant supply of nervous influence, generated by the Cerebro-spinal system, and transmitted through the Sympathetic nerve, the branches of which are copiously distributed to it. And this idea seemed to derive support from the fact, that, when the Brain and Spinal cord are removed, or when large portions of them are suddenly destroyed, by crushing or by the breaking-up of their substance in any other mode, the movements of the Heart are arrested. But it has been shown that the brain and spinal cord may be *gradually* removed without any such consequence; and the occasional production of fœtuses destitute of those centres, but possessed of a regularly-pulsating heart, is another proof that the movements of this organ do not *depend* upon a supply of nervous influence derived from them. Still they are capable of being influenced by impressions transmitted through the nerves. After the heart has ceased to beat, its contractions may be re-excited by stimulating the roots of the Spinal Accessory nerve, or of the first four Cervical nerves; the influence of that stimulation being conveyed to the heart by the Sympathetic system, the cardiac portion of which communicates with these nerves. Gentle irritation of the Par Vagum, as by the transmission of a feeble Electric current, has a tendency to accelerate the heart's action, or to re-excite it when it has ceased; yet the complete severance of both its trunks produces little disturbance in the regularity of the movement. The action of the heart may be also affected more directly through the Sympathetic system; thus it is excited by irritation of the cervical ganglia, especially the first; whilst continued pressure upon the cardiac nerve by an enlarged bronchial gland, has appeared to be the cause of its occasional suspension. It is without doubt through its nervous connections that the Heart receives the influence of mental emotions.—It has recently been supposed that the rhythmical movements of the Heart are to be regarded as *reflex* actions, of which the centres are the ganglia of the Sympathetic system dispersed through its substance. But no adequate evidence has yet been obtained of the truth of this view.

581. The movements of the Heart may be suspended or altogether checked by sudden and violent impressions on the Nervous Centres, even though these do not occasion any perceptible breach of substance; the failure of the Circulation, and consequent sus-

pension of the Sensorial functions (§ 398), constituting what is known as *Syncope.* Thus in *concussion* of the Brain there is not merely insensibility, but also a complete suspension of the circulation; this suspension may be permanent, so that animation cannot be restored; or it may be temporary, as in ordinary fainting. The well-known influence of blows upon the epigastrium in producing sudden death, is probably to be attributed to a similar cause,—namely, the shock thus communicated to the extensive plexus of ganglionic nerves radiating from the Semilunar ganglia to the abdominal viscera. Violent impressions upon other nervous expansions may produce a dangerous weakening of the heart's contractile power; this is the case, for example, with extensive burns, which may produce faintness, and even death, especially in children, by the depression which they induce; and with rupture of any important viscus. Many other causes of sudden suspension of the Heart's action might be enumerated; but they may be generally traced (as in the case of powerful emotions) to a strong impression upon the Nervous system.—It is not a little singular that while complete *suspension* of the power derived from the Nervous Centres has little influence in disturbing the Heart's action, that action should be so suddenly brought to a stand by the causes just enumerated. But we seem to have a clue to the explanation of this phenomenon in the fact ascertained by Weber, that the movements of the Heart may be immediately arrested by the transmission of a strong interrupted current (such as that of the magneto-galvanic apparatus) through one or both of the Pneumogastric nerves. We have seen that the ordinary effect of such a current transmitted through other motor nerves is to *tetanize* the muscles they supply (§ 352); but such is not the case with the Heart, which is left in a state of complete relaxation. Hence this agency is spoken of as *inhibitory;* its character being to neutralize, instead of exciting, the independent contractility of the Heart.

4. *Movement of the Blood in the Arteries.*

582. The Blood propelled from the Heart into the Arteries by a series of interrupted jets, would continue to flow in the same manner, if it were not for the equalization of its movement effected by the properties of the arterial walls. This influence is exerted by the middle or fibrous coat, which consists in part of Yellow Elastic tissue (§ 222), and in part of Non-striated Muscular fibre (§ 332). The proportion of these two components varies in Arteries of different calibre; the muscular tissue being thicker in the smaller branches, and the elastic tissue being found in larger amount in the main trunks.

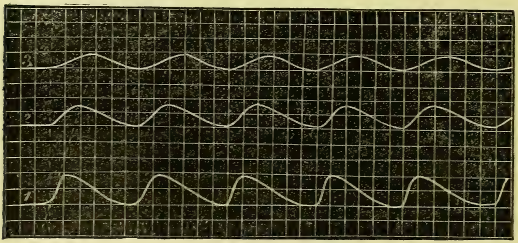
583. It is chiefly to the simple physical property of *Elasticity*

thus possessed by the Arterial tubes, that we owe the equalization of the flow of blood; and we may hence understand the reason why the trunks that are in nearest connection with the heart should be those most endowed with it. If a forcing-pump were to inject water by successive strokes into a system of tubes with perfectly unyielding walls, the flow of fluid at the farther extremities of these tubes would be as much intermittent as its entrance into them. But if the pump be connected with an air-vessel (as in the common fire-engine), so that a part of the force of each stroke is expended in compressing the air, the expansion of this, during the interval between the successive strokes, produces a continuous flow of water along the tubes. Or if the tubes themselves were endowed with a certain degree of elasticity, which should allow them to dilate near their commencement so as to receive the new charge of fluid, and which should occasion a continued pressure upon the fluid during the intervals of the stroke, the same equalizing effect would be produced.—This is precisely the case with the arterial system; the intermittent jets by which the blood is propelled from the heart are speedily converted into a continued stream, so that at even a moderate distance from the heart the only indication of its interrupted action is presented by the greater or less rapidity of the flow; and this gives rise, when an artery is divided, to an alternate rise and fall of the jet of blood, and, in the ordinary circulation, to the phenomenon called the *pulse*. This is due to an increase in the dimensions of the arterial tube, both in length and breadth, with each injection of blood; the increase in length is the more considerable of the two effects, and causes the artery to be somewhat lifted from its seat. During the intervals, a quantity of blood corresponding to that which had entered, escapes by the further extremity of the tube; and thus the artery is enabled to contract to its previous dimensions, and to return to its bed.

584. It appears from the recent researches of M. Marey, that the contraction of the Heart is felt instantly through the whole Arterial system; and that the apparent retardation in the pulse in the parts of the system most remote from the heart is not due (as has been commonly supposed) to the transmission of a 'pulse-wave' which requires *time* for travelling, but simply to the fact that the distension of the arteries attains its *maximum* earlier in those near the heart than in those more distant. This has been experimentally shown by bringing three points of a long elastic tube, through which a current of fluid was propelled by intermittent jets, under as many levers; each lever having at its opposite extremity a tracer which records on a revolving drum the degree of distension produced in the tube by the succession of jets. Such an instrument is termed a Sphygmograph. The triple tracing shown in Fig. 140 marks the effect produced at each of the

three points contemporaneously; the highest line (3) being that of the pulsations in the part of the tube most remote from the source of impulse, and the lowest (1) being that of the pulsations nearest to it. On comparing these, we note that whilst the elevation begins in all these precisely at the same moment (as is

Fig. 140.*



marked by the fact that, as we pass from left to right, the ascent commences in each case from the same vertical line), the highest point is attained soonest in the first division of the tube, and latest in the third; so that the finger placed upon the latter, taking cognizance of the maximum alone, would attribute its comparative lateness to a retardation of the entire impulse, instead of to a retardation of the maximum alone.—The character of the pulse will depend upon three distinct factors, each of which must be separately estimated:—1. The propulsive power of the Heart; 2. The degree of rigidity of the Arterial walls; and 3. The degree of facility with which the blood is propelled through the Capillaries. Of the influence of this last condition we have a very marked example in the alteration in the character of the pulse of a healthy person produced by immersion even for a minute in a cold or in a warm bath; the pulse becoming 'hard' in the former case, from the increase in arterial tension produced by the obstacle occasioned by the contraction of the cutaneous capillaries to the passage of blood through them; whilst it is made soft and bounding in the latter by the diminution in the tension of the arteries occasioned by the more ready flow of blood through the relaxed capillaries.

585. Although many Physiologists have denied that the Arteries possess real Muscular Contractility in any degree, yet there can be no longer any doubt upon the subject; since numerous experimenters have succeeded in producing distinct contraction in their walls, by the application of those stimuli which act upon muscular fibre in general, especially Electricity and Cold (§ 352).

* Tracings with M. Marey's triple Sphygmograph.

Moreover it has been ascertained that when an artery is dilated by the blood injected into it from the heart, it reacts with a force superior to the impulse to which it yielded; and that if a portion of an artery from an animal recently dead, in which the vital properties are still preserved, and a similar portion from an animal that has been dead some days, in which nothing but the elasticity remains, be distended with equal force, the former contracts to a much greater degree than the latter, after the distending force is withdrawn.—One use of this contractile power may possibly be to assist the Heart in maintaining the flow of blood; for if the Arterial walls yield rapidly to the ingress of blood, and then contract upon their contents with a force greater than that which distended them, the current must necessarily be propelled onwards with greater force. This supplementary propelling force, on the part of the arteries, may serve as a compensation to that diminution of the heart's power which must result from the increased friction of the blood against the walls of the vessels occasioned by their subdivision; and we thus observe, even in the highest animals, some traces of that diffused agency on which the Circulation is so much more dependent in the lower tribes.

586. It is now certain, however, that one chief use of the Muscularity of the Arterial walls, consists in its regulation of the diameter of the tubes, in accordance with the quantity of blood to be conducted through them to any part; the proper amount being determined by circumstances at the time. Such local changes may form a part of the regular series of actions of the human body, as when the Uterine and Mammary arteries undergo enlargement at the periods of pregnancy and parturition; and they occur still more frequently in diseases which are attended by increased action of particular organs. In such cases, it cannot be *vis a tergo* of the Heart that occasions the enlargement of certain arterial trunks, and of no others; since any increase in its propulsive power would affect all alike. It has long been surmised, from various familiar phenomena (§ 602), that the nerves of the Sympathetic system, which are copiously distributed upon the walls of the Arteries, exert an influence on their calibre by acting on their muscular coat; and this surmise has been fully borne-out by the experimental evidence of such agency which has now been obtained. Thus it has been found that while section or ligature of the Sympathetic trunk on either side of the neck, produces an enlargement of the minute arteries on that side of the face (as is best seen in the lining of the external ear of the Cat or Rabbit), accompanied with an elevation of temperature, the application of Galvanism for a minute or less causes them to contract to their ordinary calibre. The branches of the nerves which are thus distributed to the vessels are now known as *vaso-motor* nerves; and though they are directly supplied by the

Sympathetic system, yet there is reason to regard them as deriving their power originally from the Cerebro-spinal centres (CHAP. XIII., Sect. 8). It is probable, from recent enquiries, that the application of Heat and Cold to different regions of the spine, will prove an important therapeutic agent in the treatment of various functional diseases, depending upon local irregularities of the circulation which can be reached through the 'vaso-motor' system.

587. The Arterial system possesses nearly the same relative capacity in every part; that is, if a section could be made through *all* the systemic arteries at a certain distance from the heart, the united areas would be found equal to that of the aorta; while those of the branches of the pulmonary arteries would equal those of their trunk. This results from the fact that at every subdivision, the united *areas* of the branches are almost precisely equal to that of the trunk from which they proceeded; although the united *diameters* of the former far exceed that of the latter. According to a well-known mathematical law, the areas of circles are as the squares of their diameters; consequently, in making such comparisons, it is necessary to square the diameters of the trunk and those of the branches, and to contrast the former with the sum of the latter. Thus a trunk whose diameter is 7, may subdivide into two branches, each having a diameter of nearly 5; for the square of 7 is 49, and twice the square of 5 is 50. Or a trunk whose diameter is 17 may subdivide into three branches, whose diameters are 10, 10, and 9½ (making 29½ as the sum of the *diameters*); for the square of the diameter of the trunk is 289, whilst the sum of the squares of those of the branches is 290¼.—It appears, however, from Mr. Paget's measurements, that there is seldom an exact equality between the area of the trunk and that of its branches; the area sometimes increasing, and sometimes diminishing. The former seems the general rule in the upper extremities; the latter in the lower. Thus the area of the trunk of the external carotid is to that of its branches as 100 to 119; whilst the area of the abdominal aorta, just before its final division, is to that of its branches as 100 to 89. On the whole, it appears that the lateral pressure of the blood upon the walls of the Arteries diminishes towards the periphery of the system; showing that the aggregate area of the branches must be greater than that of the trunks.

588. In almost every part of their course, the ramifications of the Arteries communicate freely with each other by *anastomosis;* and this communication is most important, as affording the means by which the circulation is sustained when the current through the main trunk is obstructed. There is scarcely an artery in the body, except the aorta, which may not be tied, with the certainty that the blood will still be conducted to its destination by the

collateral circulation. The quantity which thus passes is at first very insignificant, and it is by no means sufficient to supply what is needed; thus, when the femoral artery has been tied for popliteal aneurism, the limb becomes cold, and the sensibility of its surface and its muscular power are alike diminished. In a few hours, however, its warmth returns, and its sensibility and muscular power are restored; indicating that its circulation has been already re-established through the collateral branches. And where an opportunity presents itself at a subsequent period for examining the state of the vessels in such a limb, it is found that an extraordinary enlargement has taken-place in arteries that were previously of insignificant size, which form a communication between the branches that issue above and below the interruption. Moreover, it is commonly found that the main trunk has become completely impervious above the part where it was obliterated by the ligature, up to the point at which the nearest lateral branch is given-off.—Even the abdominal aorta has been tied in dogs, without fatal results; the circulation in the posterior part of the body and in the hinder extremities, being then maintained chiefly by the inosculation of the external mammary artery with the epigastric, upon the parietes of the abdomen.

589. The rate of movement of the blood in any artery can only be guessed at, as regards the Human subject, from the results of experiments on the lower animals; and there is not yet any such agreement among these, as would justify a very positive statement. From 10 to 20 inches per second, in the Carotid of Man, seems the probable rate of the current; its rapidity during the Ventricular systole being much greater than during the diastole.

5. *Movement of Blood in the Capillaries.*

590. The general characters by which the Capillaries are distinguished from the Arteries which deliver their blood into them, and from the Veins which carry off the blood that has traversed them, having been already described (§ 318), we are now chiefly concerned with the phenomena of the Circulation carried on through them. The average rate at which this takes-place in warm-blooded animals seems to be about 1·8 inch per minute, or ·03 inch per second; and comparing this with the rate of movement in the larger Arteries, it has been estimated by Vierordt that the aggregate area of the Capillaries must be as much as 800 times as great as that of the Arteries which supply them. This is not surprising when we note the extraordinary minuteness of the Capillary network in the more vascular tissues (Figs. 141, 142).

591. The term 'Capillary' may be employed in an extended or a restricted sense; in the former it includes *all* the minute vessels which pass between the arteries and the veins; in the latter it is

applied only to those which admit no more than a single file of blood-disks at once, and excludes those which admit two, three, or even four rows, even although they establish a direct communication from one side of the network to the other. The former application of the term is the most convenient, although, perhaps, not the

Fig. 141.*

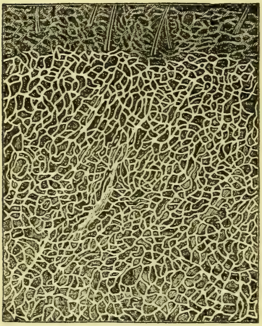
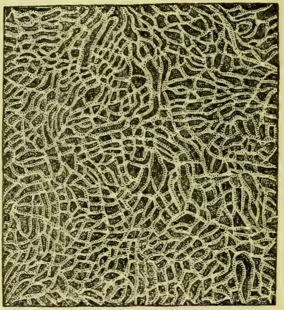


Fig. 142.†



most strictly accurate; and it will be here employed, therefore, in its extended sense. And this is rendered more correct by the fact, that the size of the individual capillaries is by no means permanent; an enlargement often taking-place in one, and a contraction in another, at the same time: so that vessels which were previously true capillaries, no longer remain such; and passages which were previously of far greater calibre, are reduced to the average diameter.

592. That the blood can only minister to the operations of Nutrition, Secretion, &c., whilst it is circulating through the Capillaries, is evident from several considerations. The thickness of the walls of the larger vessels interposes an effectual barrier to its transudation; and so completely is the blood cut-off even from penetrating these, that they do not derive their own nourishment from the blood which flows through their tubes, but from a capillary network in their own substance, which is supplied by vessels from collateral branches,—these being termed the *vasa vasorum*. Moreover it is by the inosculation of the capillaries alone that the minute network is formed, which serves to bring the blood into proximity with the minute parts of the tissues to be nourished; thus, let it be supposed that the minute arteries of

* Capillary Network in simple Mucous Membrane of palpebral conjunctiva.
† Capillary Network in Choroid coat of the eye.

Muscle were to terminate in veins, without undergoing further subdivision, the *islets* left between their anastomosing branches would be far too large, and the nutritive materials would consequently not be supplied with sufficient readiness, even supposing that it could freely permeate the walls of these vessels.—The Capillaries, then, must not be regarded as altogether distinct in their endowments from the vessels with which they are connected on either side; but merely as intended, by their minute subdivision and inosculation, to bring the blood into sufficiently close relation with the tissues they are to nourish, and to allow a greater degree of transudation of its elements by the comparative thinness of their walls.

593. When the flow of blood through the Capillaries of a transparent part, such as the web of a Frog's foot, is observed with the Microscope, it appears at first to take-place with great evenness and regularity. The influence of the contractions of the heart may be seen to extend itself into the smaller arteries; the blood moving onwards in them with a somewhat jerking motion. But this influence altogether disappears in the capillary network; the flow of blood through this being even and continuous, except when the action of the heart is becoming weak and irregular, or when its influence is impeded by obstruction in the vessels leading to the part,—the blood being then impelled by a succession of jerks, with intervals of complete repose. On watching the movement for some time, however, various changes may be observed which cannot be attributed to the heart's influence, and which show that a certain regulating or distributive power exists in the walls of the capillaries, or in the tissues which they traverse. Not only do we occasionally perceive some of the tubes enlarging, so as to admit several files of blood-disks instead of one, whilst others that previously received several now only admit one; but we also see vessels coming into view which were not previously noticed, whilst other vessels seem to become obliterated. This apparently new formation and obliteration of vessels, however, does not really take-place; for a more close examination shows that the former of these appearances is due to the entrance of red corpuscles into passages which existed before, but which were in such a state of contraction as enabled them only to admit the fluid portion of the blood: whilst, by a converse change in certain capillaries from the dilated to the contracted state, the appearance of obliteration is produced, the red corpuscles being excluded, and the transparent fluid of the blood being alone transmitted by them.

594. But these are by no means all the irregularities which may be detected by a close scrutiny of the Capillary circulation. The velocity of the current is liable to great and sudden variations, which cannot be accounted-for by any change in the heart's action,

or in the supply of blood afforded by the arteries ; and this change may manifest itself either in the whole capillary network of a part, or in a portion of it; the circulation taking-place with diminished rapidity in one part, and with increased energy in another, though both are supplied by the same trunk. These variations are sometimes manifested by a complete change in the direction of the movement in certain of the transverse or communicating branches; this movement taking-place, of course, from the stronger towards the weaker current. Not unfrequently an entire stagnation, of longer or shorter duration, precedes the reversal of the direction. Irregularities of this kind are most frequent when the heart's action is enfeebled or partially interrupted; and it would thus appear that the local influences by which they are produced are overcome by the propelling power of the central organ, when this is acting with its full vigour. When the whole current has nearly stagnated, and a fresh impulse from the heart renews it, the movement is seldom uniform through the entire plexus supplied by one trunk; but is much greater in some of the tubes than in others,—the variation being in no degree connected with their size, and being very different in its amount at short intervals.

595. All these circumstances indicate that the movement of blood through the Capillaries is very much *influenced* by local forces; although these forces are not sufficiently powerful, in the higher animals, to *maintain* it alone. And from other facts it appears that the conditions necessary for the energetic flow of blood through these vessels, are nothing else than the active performance of those nutritive and other operations to which they are subservient. The examination of a single one of these processes will afford us the requisite proof. The blood when circulating through the *systemic* capillaries, yields a portion of its oxygen to the tissues it permeates, and receives from them carbonic acid. On the other hand, when passing through the *pulmonary* capillaries, it gives-up its carbonic acid to the atmosphere, and imbibes a fresh supply of oxygen. Now if either of these changes be prevented from taking-place, a retardation and even a complete stagnation of the blood will occur,—the flow through the capillaries being now resisted, instead of accelerated, by the relation which the blood bears to the tissues.

596. Thus it has been shown that if an animal be partially deprived of oxygen, so that the arterial blood is not duly aërated (rather resembling the ordinary venous blood), and cannot exert its proper action on the tissues, the pressure upon the walls of the systemic arteries is *increased*, although the supply of blood propelled by the heart, and the propulsive power of the heart itself, are *diminished;* and this plainly indicates a retardation in the systemic capillaries, producing an undue accumulation in the arteries.—On the other hand, the complete suspension of the

supply of oxygen to the lungs, either by an obstruction in the air-passages, or by the substitution of some other gas, brings the pulmonary circulation to a stand in a very short time, the blood not being able to undergo its usual changes in the capillaries of those organs; and by this stagnation, the whole movement of blood is speedily checked. The readmission of oxygen, if the suspension of the circulation have not been too long continued, occasions the renewal of the movement in the capillaries, and thence in the whole circle of vessels; and this even after the heart has ceased to propel blood towards the lungs.

597. A physical principle has been put forth by Prof. Draper, which seems adequate to the explanation of these phenomena. "If two liquids communicate with one another in a capillary tube, or in a porous or parenchymatous structure, and have for that tube or structure different chemical affinities, movement will ensue; that liquid which has the most energetic affinity will move with the greatest velocity, and may even drive the other before it." We have already seen that such a current is produced by a mere difference in the power of the two liquids to 'wet' the porous medium (§ 492); and it seems reasonable to attribute a much greater power to differences of Chemical affinity. Now Arterial blood,—containing oxygen with which it is ready to part, and being prepared to receive in exchange the carbonic acid which the tissues set-free,—must obviously have a greater affinity for the walls of the systemic capillaries than the Venous blood in which both these changes have been already effected. Consequently, upon mere physical principles, the arterial blood which enters the systemic capillaries on one side, must drive before it, and expel on the other side of the network, the blood which has become venous whilst traversing it. But if the blood which enters the capillaries have no such affinity, no such motor power can be developed.—On the other hand, in the Pulmonary capillaries the opposite affinities prevail. The venous blood and the air in the pulmonary cells have a mutual attraction, which is satisfied by the exchange of oxygen and carbonic acid that takes-place through the walls of the capillaries; and when the blood has become arterialized, it no longer has any attraction for the air. Upon the very same principle, therefore, the Venous blood will drive the Arterial before it in the pulmonary capillaries whilst respiration is properly going-on: but if the supply of oxygen be interrupted, so that the blood is no longer aërated, no change in the affinities takes-place whilst it traverses the capillary network; the blood, continuing venous, still retains its need of a change and its attraction for the walls of the capillaries; and its egress into the pulmonary veins is thus resisted, rather than aided, by the force generated in the lungs.

598. The change in the condition of the Blood in regard to the

relative proportions of its Oxygen and Carbonic acid, is the only one to which the Pulmonary circulation is subservient; but in the Systemic circulation the changes are of a much more complex nature, every distinct organ attracting to itself the peculiar substances which it requires as the materials of its own nutrition; and the nature of the affinities thus generated will consequently differ in each case. The same law holds-good, however, in all instances. Thus the blood conveyed to the liver by the portal vein, contains the materials at the expense of which the bile-secreting cells are developed; hence the tissue of the liver, which is principally made-up of these cells, possesses a certain degree of affinity or attraction for blood containing these materials; and this is diminished, so soon as they have been drawn from it into the cells around. Consequently, the blood of the portal vein will drive before it, into the hepatic vein, the blood which has traversed the capillaries of the portal system, and which has given-up, in doing so, the elements of bile to the solid tissues of the liver.

599. We are now prepared, therefore, to understand the general principle, that the rate of the Circulation in any part will depend in great measure upon the activity of the functional changes taking-place in it,—the heart's action, and the state of the *general* circulation, remaining the same. When, by the heightened vitality or the unusual exercise of a part, the changes which the blood naturally undergoes in it are increased in amount, the affinities which draw the arterial blood into the capillaries are stronger, and are more speedily satisfied, and the venous blood is therefore driven-out with increased energy. Thus a larger quantity of blood will pass through the capillaries of the part in a given time, without any enlargement of their calibre, or even though it be somewhat diminished; but the size of the arteries by which it is supplied soon undergoes an increase, which adapts it to supply the increased demand. Any circumstance, then, which increases the functional energy of a part, or stimulates it to increased nutrition, will occasion an increase in the supply of blood, altogether irrespectively of any change in the heart's action. This principle has long been known, and has been expressed in the concise adage, "Ubi stimulus, ibi fluxus;" which those Physiologists who maintain that the Circulation is maintained and governed by the Heart alone, cast into unmerited neglect.

600. An undue acceleration of the local circulation, arising from an excess of functional activity in the part, and unaccompanied by any other change, constitutes the state known as *active congestion*, or *determination of blood*. This may be artificially produced by the application of gentle stimulants; and it is usually the first change that occurs when their action proves sufficiently violent to produce Inflammation. From that state, however, it

is distinguished by this important character,—that there is merely an *exaltation* of the *natural* function, but no *change.* Moreover, when the state of Inflammation is developed, there is a stagnation of blood instead of acceleration, and *depression* or *change* of its function. We frequently meet with cases in which this active congestion becomes very manifest; especially in persons of active minds who exert their mental powers too violently, and who thereby induce an habitually-increased flow of blood towards the head, manifested in the increased pulsation of the carotids, the suffusion of the face and eyes, and the heat of the surface. The balance of the circulation being thus disturbed, there is almost invariably a diminished energy of the movement of blood in other organs, especially the extremities ; as is indicated by their habitual coldness and lividity. In the treatment of such a state (which is often the precursor of serious disease), it should be our object to restore the circulation in the extremities by friction, exercise, &c.; and to abate the flow of blood towards the head by restraining the functional activity of the brain, by the application of cold to the surface, by keeping the head high during sleep, and other means of similar tendency.

601. There is another condition of the Capillary circulation, also known under the name of *Congestion*, which is precisely the opposite of the preceding. In this state there is deficient functional energy in the part, and the circulation through it is consequently retarded,—as we have seen it to be in the Lungs when there is a partial obstruction to the aëration of the blood. With this there is usually a deficiency in the rigidity of the walls of the Arteries, so that they are unduly distended by the *vis a tergo* of the blood; and consequently there is a great accumulation of blood in the part, with a retarded movement. This condition, like the preceding, predisposes to Inflammation, although in a different mode. It is relieved by causes which promote the action of the part; thus congestion of the lungs, occasioned by the effusion of fluid into the air-cells, which creates an obstacle to the aëration of the blood, disappears when that effusion is absorbed. And congestion of the liver, the result of deficient secreting power in the organ, is relieved by mercurial and other medicines, which promote the flow of bile by stimulating the action of the hepatic cells.

602. The Capillaries, like the Arteries, possess a power of contraction and dilatation, which seems to be very much under the influence of the Nervous System, and particularly of that part of it which conveys the influence of the Emotions. We have a *visible* example of this influence in the act of *blushing*, which consists in a sudden enlargement of the capillaries and small vessels of the surface; whilst the converse state of *pallor*, which often alternates with it under the influence of strong emotion, is

due to an unusual contraction of the same vessels, except in cases in which there is a failure of the Heart's power. But the effects of this influence are no less sensible in other cases; and particularly in the regulation of the quantity of certain Secretions, in accordance with the mental state or with the condition of the system generally. To the mode in which this regulation is effected, we seem to have the key in the proved influence exerted by the vaso-motor nerves in regulating the calibre of the Arteries (§ 586); thus the nursing mother, at the sight or even at the thought of her child, when the usual time for suckling approaches, feels a rush of blood to the breast, exactly resembling that which takes-place to the cheeks in blushing, and popularly termed 'the draught'; this rush occasions an almost immediate increase in the secretion. In like manner we may explain the influence of the mental state upon the *amount* of the secretions of the Lachrymal, the Salivary, and many other glands; its influence upon their *quality* must probably be effected through changes in the condition of the blood itself.

603. The supply of Nervous agency from the Cerebro-spinal system, has been clearly proved to exert no direct influence in maintaining the Capillary circulation; since the latter continues as usual, after all the nerves of a part have been divided. This is obviously due to the fact, that the operations of nutrition, secretion, &c., are essentially independent of this agency (§ 618). But as *they* are in some degree *influenced* by it, so will the capillary circulation be affected through its connection with them. In this manner we are to explain the effect of violent impressions upon the nervous centres, in bringing to a stand, not merely the action of the Heart (§ 581), but the Capillary circulation all over the body. The general vitality of the system appears to be at once destroyed; so that the capillary circulation, which may usually be seen to continue in the web of a frog's foot for some moments after the interruption of the heart's action, is immediately suspended by crushing the brain with a hammer.

6. *Of the Movement of Blood in the Veins.*

604. The Venous system is formed by the reunion of the small trunks which originate in the capillary network; and it carries back to the heart the blood which has been transmitted through this. Such blood is *dark* or carbonated in the *systemic* veins; whilst it is *bright* or oxygenated in the *pulmonary* veins.—The structure of the veins is essentially the same with that of the arteries; but the fibrous tissue of their middle coat less decidedly exhibits the characters, either of the yellow elastic tissue, or of non-striated muscle. Still it possesses no inconsiderable amount of Elasticity; and a certain degree of Muscular contractility also.—The

whole capacity of the Venous system is at least *twice*, and perhaps more nearly *three times*, that of the Arterial; and the rate of motion of the blood in it must be proportionably slower.

605. The movement of the Blood through the Veins is, without doubt, chiefly effected by the *vis a tergo*, or propulsive force, which results from the contractile power of the heart and arteries, aided by the power generated in the capillary vessels. The intermittent flow which is caused by the interrupted action of the former, is usually so far equalized during the passage of the blood through the capillary network, that no pulsation can be shown to exist in the veins; but instances occasionally present themselves in which a venous pulse may be clearly perceived.

606. The Venous Circulation is affected, however, by certain other causes, which exert little influence on the movement of blood in the Arteries. One of these is the frequently-recurring action of Muscles, to which the Veins are peculiarly subject, on account of their position. In every instance in which Muscular movement takes-place, a portion of the Veins of the part will undergo compression; and as the blood is prevented by the valves in the veins from being driven-back into the small vessels, it is necessarily forced-on towards the heart. As each set of muscles is relaxed, the veins that were compressed by it fill-out again, to be again compressed on the renewal of the force. Thus we see how the general Muscular movements of the body have an important influence in maintaining the Venous Circulation,—how continued exercise, involving the alternate contraction and relaxation of several groups of muscles, must send the blood more rapidly towards the heart, and thus increase the rapidity of its pulsations,—and how the sudden and simultaneous action of a large number of muscles after repose (as when we rise-up from the sitting or lying, to the standing posture), may drive the blood to the heart with so violent an impetus, as to produce even fatal results, if, by any diseased condition of that organ, it should be rendered unable to dispose with sufficient rapidity of the quantity of blood thus transmitted to it.

607. The Respiratory movements exert a slight influence upon the flow of blood through the large Veins near the heart; for as the chest is a closed cavity, in which a partial vacuum is produced by the act of Inspiration, whilst its contents are compressed by the act of Expiration, the former state will favour the movement of blood from the large veins on the exterior of the cavity towards the heart, whilst the latter condition will retard it. This produces the phenomenon termed *respiratory pulse;* which may be seen in the veins of the neck and shoulders in thin persons, and especially in those who are suffering from pulmonary diseases. The influence of the Respiratory movements is made evident by introducing a tube into the Jugular vein, the lower end of which

dips into water; for an alternate elevation and depression of the water into the tube is then witnessed, showing the suction-power of the Inspiratory movement, and the expellent force of the Expiratory act.—On the other hand, the Expiratory movement, while it directly tends to cause accumulation in the Veins, will assist the heart in propelling the blood in the Arteries; and by the combined action of these two causes there is produced, among other effects, a rising and sinking of the Brain, synchronously with expiration and inspiration, which are observed when a portion of the cranium is removed.

608. A pulsatory movement may be occasioned in the great Veins near the heart, by another cause entirely distinct from the preceding;—namely, the regurgitation of blood from the ventricle into the auricle, and thence into the venæ cavæ, during the *ventricular* systole; and the pulsation thus occasioned is synchronous, therefore, with that in the arteries (proceeding *backwards*, however, from the heart), instead of corresponding with the respiratory movement. This regurgitation may take-place, not from any disease in the valves on the right side of the heart, but simply from over-distension of its cavities, resulting from any obstruction to the circulation of blood through the lungs; for when this occurs, the tricuspid valve does not completely close, and allows a portion of the blood to escape from the ventricle backwards into the auricle and venæ cavæ. This want of complete closure, constituting what has been termed the 'safety-valve function' of the tricuspid valve, has been particularly noticed in diving animals, in which the circulation through the lungs is liable to be temporarily suspended. The venous pulsation which is thus produced, may be noticed in almost every case of long-standing dyspnœa; especially when this is accompanied (as it usually is) by hypertrophy and dilatation of the right ventricle of the heart.

609. The Venous circulation is much more liable than the Arterial, to be influenced by the force of Gravity; and this influence is particularly noticeable when the Tonicity of the vessels is deficient. The following experiments performed by Dr. Williams, to elucidate the influence of deficient firmness in the walls of the vessels, and of gravitation, on the movement of fluids through tubes, throw great light on the causes of Venous Congestion.—A tube with two equal arms having been fitted to a syringe, a brass tube two feet long, having several right angles in its course, was adapted to one of them, whilst to the other was tied a portion of a rabbit's intestine four feet long, and of calibre double that of the brass tube, this being arranged in curves and coils, but without angles and crossings. When the two ends were raised to the same height, the small metal tube discharged from two to five times the quantity of water discharged in a given time by the larger but membranous tube; the difference

being greatest when the strokes of the piston were most forcible and sudden, by which the intestine was much dilated at its syringe-end, but conveyed very little more water. When the discharging ends were raised a few inches higher, the difference increased considerably, the amount of fluid discharged by the gut being much diminished; and when the ends were raised to the height of eight or ten inches, the gut ceased to discharge, each stroke only moving the column of water in it, and this subsiding again, without rising high enough to overflow. When the force of the stroke was increased, the part of the intestine nearest the syringe burst.

610. From these experiments, it is easy to understand how any deficiency of firmness in the walls of the Veins will tend to prevent the ascent of the blood from the depending parts of the body, and will consequently occasion an increased pressure on the walls of the vessels, and an augmentation in the quantity of blood they contain. All these conditions are peculiarly favourable to the escape of the watery part of the blood from the small vessels; and this may either infiltrate into the connective tissue, or it may be poured into some neighbouring serous cavity, producing dropsy. Thus it happens that such effusions may often be traced to that state of deficient vigour of the system, which peculiarly manifests itself in want of 'tone' of the blood-vessels, and that it is relieved by remedies which tend to restore this. In many young females of leuco-phlegmatic temperament, for example, there is a tendency to swelling of the feet by œdematous effusion into the connective tissue, in consequence of the depending position of the limbs; the œdema disappears during the night, but returns during the day, and is at its maximum in the evening. And the congestion which frequently manifests itself in the posterior parts of the body, towards the close of exhausting diseases in which the patient has lain much upon his back, is attributable to a similar cause; of such congestion, effusions into the various serous cavities are frequent results; and such effusions, taking-place during the last hours of life, are often erroneously regarded as the cause of death. To the same cause we are to attribute the varicose state of the veins of the leg, which is so common amongst persons of relaxed fibre, and especially in those whose habits require them to be much in the erect posture; and this distension occasionally proceeds to complete rupture, the causes of which are fully elucidated by the experiments just cited.

611. It has been thought that the circulation within the Cranium is subject to different conditions from that of other parts of the body. For it has been argued that, as the cranium is a closed cavity,—a certain part of which is occupied by the cerebral substance and its membranes, and the remainder filled-up with blood,—the amount of blood in the vessels of the Brain must be

always the same, so that any disturbance of its circulation must be due to a difference in the relative quantity of blood in the Arteries and the Veins. This idea appeared to derive support from the results of experiments, which showed that the blood is retained in the vessels within the cranium of animals bled to death, unless an opening be made in the skull, so as to allow the air to exert the same pressure upon these vessels as upon those of other parts. But such experiments do not at all sanction the assertion that the quantity of blood within the cranium is constant; on the contrary, we have reason to believe that it undergoes as much change as in other parts. For although the cerebral substance is incompressible, yet its bulk is subject to constant variation according to the quantity of fluid it contains; and the presence of the 'cerebro-spinal fluid' in the sub-arachnoid cavity of the brain and spinal cord, appears to be peculiarly destined to favour this continual change,—the proportions of it contained in the spinal and the cerebral cavities respectively, being governed by the bulk of the other contents of the cranium. Thus if the vessels of the cerebrum be in their ordinary state of fulness, a certain amount of fluid is present in the sub-arachnoid cavity of the brain; this will be pressed-out into the spinal portion of the cavity, if the cerebral vessels be unusually distended with blood; whilst it will be increased from the latter source, so as to fill-up the vacant space within the cranium, if the cerebral vessels be unusually empty.

612. There is a peculiarity in the structure of the Veins in the *Erectile* tissues, which requires special notice. The chief seats of these are the corpora cavernosa in the penis of the Male and the clitoris of the Female, the collection of similar substance round the vagina and in the nymphæ of the Female, and the nipple in both sexes. They essentially consist of a plexus of veins with varicose enlargements, enclosed in a fibro-muscular envelope, having internal prolongations of the same material which pass across in every direction; and there is reason to believe that the blood is delivered into these by special arterial branches, distinct from those which terminate in the ordinary capillary network. Erection may be produced on the one hand by mental states, on the other by local excitement; of the latter we have a familiar example in the erection of the nipple induced by moderate cold, as in putting on a clean shirt. In either case, it is probable that the immediate stimulus to the action is conveyed through the Nervous system; and experimental evidence of this has been obtained as regards the erection of the penis, which has been found by Eckhard mainly to depend upon the agency of the *nervi erigentes* proceeding from the sacral veins and entering the hypogastric plexus, and the *nervi pudendales communes* proceeding from the sciatic plexus. On exposing and irritating the former, tumefaction of the penis immediately commenced, and gradually pro-

ceded forwards to the glans. On the other hand, after division of the latter, Eckhard found it impossible to produce either erection of the penis or *emissio seminis* by direct irritation of the penis. Not improbably the former is the 'efferent' nerve which immediately acts on the erectile tissue; whilst the latter may be the 'afferent' nerve through which the effects of local irritation are conveyed to the nervous centres. It seems probable that the effect of the nervous stimulus is here, as in blushing (§ 602), to *relax* the muscular contraction which at other times prevents the blood from filling the cavernous veins; but there is evidence that, in the case of the penis, the *contraction* of the ischio-cavernosi and bulbo-cavernosi muscles completes and strengthens the erection by compressing the veins which return the blood from the penis, though this contraction will not of itself effect the erection.

CHAPTER VIII.

OF NUTRITION.

1. *Formative Power of Individual Parts.*

613. THE Blood which is carried into the different parts of the system by the Circulating apparatus, is the source from which all the organs and tissues of the body derive the materials of their growth and development; and, as we have seen, it is distributed by the Capillaries of the several tissues, with a degree of minuteness which varies according to the activity of the nutrient operations in the respective parts. Thus in Nerve and Muscle, Mucous Membrane and Skin, a constant decay of the old and a development of new tissue are taking-place whilst these organs are in a state of functional activity, and a copious supply of blood is carried through every part of their substance: whilst in Cartilage and Bone, Tendon and Ligament, the amount of interchange is very small, and is affected by a much less minute reticulation of capillary blood-vessels.

614. The *materials* of the nutritive process being prepared in the Blood, the process of nutrition is the act of each individual part; which grows and developes itself in virtue of its own inherent powers, so long as the requisite conditions are supplied. The mode in which this takes-place in each individual tissue, has been already explained in the former part of this Treatise. We have seen that the act of Nutrition primarily consists in the augmentation of the 'germinal matter' which is the originator of all kinds of 'formed material;' that this germinal matter draws into itself certain components of the Blood, just as the sarcodic network of

the Rhizopod draws into itself the alimentary particles furnished by the medium through which it spreads itself out; and that while undergoing increase of substance at the expense of the new material thus appropriated, the 'germinal matter' multiplies by subdivision the number of its independent segments; every one of which has an individual activity of its own. These germinal segments develope cells, fibres, or other kinds of 'formed material,' according to the mode of activity peculiar to each group; each drawing from the circulating current the particular components it may require for its special product. Thus the 'germinal matter' that gives origin to Bones and Teeth must take up from the Blood a large proportion of Phosphate of Lime, that of Fat-cells must especially appropriate oleaginous matter, and so on. 'Formed material' of every kind seems to be entirely destitute of the power of self-increase, this being the attribute of 'germinal matter' or protoplasmic substance alone; hence its augmentation can only take place at the expense of the latter, which is, as it were, the builder-up of the entire fabric.*

615. The *selective power* which is possessed by the germinal segments of each kind of tissue, and which enables them to draw from the blood the materials which they severally require for their development, manifests itself peculiarly in the mode in which substances that are abnormally present in the blood affect the condition and development of the solid tissues. Thus we find that the presence of a certain quantity of Arsenic in the blood, will produce a state of irritation in all the Mucous membranes of the body. The continued introduction of Lead into the circulating system occasions a modification in the nutrition of the extensor Muscles of the forearm, producing the form of partial paralysis commonly termed 'wrist-drop;' and the existence of this modification is shown by the presence of lead in the paralysed muscles. Here we have to remark the *symmetrical* nature of the affection, consequent upon the occurrence of the same disorder in the corresponding parts of the two sides of the body; for these muscles appear to have the same kind of tendency to attract lead from the circulating current in a degree that is equal on the two sides, as they have to draw from the blood the materials of their regular growth so as to develope themselves in an exactly similar manner. In like manner, the cutaneous eruptions which are occasionally produced by the internal exhibition of iodide of potassium, are found to be almost precisely symmetrical; the presence of the

* In adopting to this extent the views of Prof. Beale, the Author cannot go the length with him of asserting that all 'formed material' has lost its vitality; since it does not follow that in losing its power of self-increase, it has thereby lost the other attributes which distinguish it as a living structure. Nothing, for example, can more characteristically exhibit *vital* properties, as distinguished from any that can be ascribed to its Physical or Chemical nature, than *Muscular Fibre*; yet this belongs to the category of 'formed material.'

medicine in the blood being the occasion of a disordered nutrition of certain parts of the skin, and the selecting power of particular spots being evinced by the exact correspondence of the parts affected on the two sides.

616. The like selective power appears to be exerted with regard to other substances, whose presence in the blood is rather the result of a disordered condition of the digestive and assimilating processes, than of their direct introduction from without. Thus in Lepra and Psoriasis,—chronic diseases of the Skin, which seem to have their origin in a depraved state of the blood, rather than in the solid tissues affected,—we find a remarkable tendency to the repetition of the patches on the two sides of the body, or on the corresponding parts of the limbs; and this we can attribute to nothing else than the peculiar attraction existing between the solid tissues of those parts and the morbid matter circulating through them. So in those chronic forms of Gout and Rheumatism which modify the nutrition of the joints, producing a deposit of 'chalk-stones' or permanent distortion and stiffening, we almost invariably find the corresponding joints of the two sides affected. The chief exceptions to the general principle that the presence of morbid or extraneous matters in the blood affects corresponding parts alike, are found to exist where there is active disturbance, or where local causes produce a peculiar tendency to disorder of a single part. The nearer the character of the morbid process is to that of the ordinary nutritive operations, the more nearly does it approach these in the *symmetry* with which it developes itself.*

617. For the due performance of the act of Nutrition, it is obvious from what has preceded that *a right state and composition of the Blood* must be a fundamental condition. Not only must the blood be able to supply the materials required for the development of each tissue in a state of due preparedness, but it must be free from any taint which can interfere with the right appropriation of these materials by the tissue itself (§§ 615, 616). Further, the supply must be *adequate in amount*. But a condition of not less importance is the *normal state of the part to be nourished;* and especially its possession of a right measure of 'formative capacity,' in virtue of which the newly-produced tissues are generated in the likeness, as well as in the place, of those which have become effete. The exactness of this replacement is most remarkably shown in the retention of the characteristic form and structure of each separate organ or part of the body through a long series of years; not only the general type of the species, but the distinctive peculiarities of the individual being thus maintained; and even acquired peculiarities being thus kept up in

* See Dr. W. Budd's valuable Paper on the "Symmetry of Disease," in Vol. xxv. of the Medico-Chirurgical Transactions, and Mr. Paget's Lectures on Surgical Pathology.

some instances, as in the perpetuation of a cicatrix left after the healing of a wound, and in the tendency to the renewal of a morbid action which has once established itself in a part, even though a healthy state of nutrition may have been for a time restored. A deficiency of 'formative capacity' involves the *atrophy* of the part, however abundant may be the supply of material for its nutrition; and a general decline of this 'formative capacity' throughout the system at large is a common cause of death in advanced life, when there is no special disease. We shall presently see (§ 622) that partial or complete atrophy of particular organs takes place from time to time, as a part of the cycle of changes in which the life-history of each individual consists; and it is liable to occur in any organ which may be entirely deprived of its functional activity. Thus, in the Rabbit whose sciatic nerve had been divided seven weeks previously by Dr. John Reed (§ 343), not merely had the weight of the muscles diminished from 327 grains to 170 grains, but that of the Bones had diminished from 89 grains to 81 grains,—a remarkable proof that even in the most solid tissue of the body a degeneration is continually going on, which will manifest itself sensibly in a short time if not antagonized by the Nutritive process.

618. Much discussion has taken place upon the question how far the process of Nutrition is affected by the Nervous system; some Physiologists maintaining that nervous influence is essential to its performance, whilst others hold that the Nutritive operations are not more *dependent* upon nervous agency in the Animal than they are in the Plant, although, like the Secretory, subject to its influence. Of the potency of such influence we have many illustrations; on the one hand, in the modification which may be produced in the Nutrition or Secretion of a part by certain states of mind; on the other, in the effect of the interruption of nervous supply to a part by section of its nerves or by pressure on their trunks. Thus it is a fact admitting of no question that the continual direction of the *Attention* (especially if connected with some Emotional feeling) to a part may alter its mode of nutrition;—either for the worse, as we see in Hypochondriasis,—or for the better, as in the case of those undoubted cures (sometimes of serious maladies) which are popularly set down to the influence of Imagination. In either case, such agency can only be exerted through the Nervous System. Again, it is a matter of frequent observation that the interruption of nervous supply to a part is followed by impairment of its nutrition. But we are not always justified in attributing this impairment to the simple withdrawal of nervous power; for it may be due either to the suspension of the functional activity of the part (as in the case just referred to, § 617), or to the want of power of withdrawal from external agencies tending to its deterioration. Of the latter *modus operandi*

we have a marked example in the effects of paralysis of the posterior extremities produced by section of the Spinal Cord in the lumbar region. It was formerly believed that this operation *must* be fatal to Rabbits, Guinea-pigs, &c., in consequence of the sloughing of the limbs which was supposed to be a necessary consequence of it. But it has been shown by M. Brown-Séquard that if due care be taken to protect the paralyzed limbs from injurious influences, there is no more serious deterioration of their nutrition than that which necessarily results from their disuse; and even that the animals may thus be kept alive until the limbs are brought into play again by the restoration of the functions of the Spinal Cord.—But after making every allowance on this score, we find that Pathological observation supplies facts incapable of any other explanation, which indicate the existence of a very decided influence on the part of the nervous system over the Nutrition of the organism. These facts, however, do not in the Author's opinion prove anything more than the existence of such a *modifying and controlling influence* as the rider exerts upon the actions of his horse, or the engine-driver upon those of his locomotive; the *power* which really does the work having its source, in the Animal, as in the Plant, in the Force derived from the Heat that is either generated in the organism or is supplied from without.

2. *Varying Activity of the Nutritive Processes.*

619. The nutritive operations present very great variations in their relative activity under different circumstances. As a general rule, it may be stated that the greater the demand for the functional activity of the organ or tissue, the more energetic is its nutrition; and *vice versâ*. Now this is readily understood, when it is considered that the active state of many structures essentially consists in an act of nutrition; thus the energy of the Secreting processes is in many instances dependent upon the growth of the secreting cells which make-up the essential part of the gland; and the energy of the Assimilating processes is dependent upon the development of the cells which elaborate the nutrient matter. This growth is regulated mainly by the supply of blood; being increased by the afflux of blood towards the part, in consequence of the influence of the nerves upon the vessels, or through any other change in the current of the circulation. Thus the secretions are augmented in amount by emotions of the mind, that act (probably through the Sympathetic nerve) in regulating the calibre of the arteries supplying their respective glands; or the interruption of the function of one gland shall occasion an increased nutrition, and consequently an augmented secretion in its fellow,—as when one of the Kidneys is hypertrophied through a disease in the other, that renders it incapable of performing its

office. Still it would appear that there may be variations in the activity of these organs, resulting from causes inherent in themselves (of the nature of which we know little or nothing): and that here as elsewhere, active nutritive operations will promote the circulation of blood through the part, whilst a languid state of their function will retard it.

620. In certain other tissues, however, the functional activity would seem rather to involve a *waste* or *decay* of structures previously developed: this is the case especially in Nerve and Muscle, which are found to undergo disintegration in proportion to the degree in which they are exercised; whilst the degree in which this waste is repaired depends upon the supply of nutritive material, the quiescent state of the part, and other circumstances. But even here we find that functional activity occasions increased nutrition, in the same manner as burning a lamp with a high flame increases the amount of fluid drawn-up by the wick. For neither the nerves nor the muscles can act with energy without a large supply of arterial blood: and this is drawn to them by the agencies already mentioned (§ 599) as increasing the energy of the local circulation. The determination of blood to the parts thus established, favours their increased nutrition; and thus we find that, under favourable circumstances, any set of muscles which is habitually exercised undergoes a great increase of development; whilst, in like manner, the Nervous centres, if too great a demand be made upon their activity, are liable to become hypertrophied (especially in young persons), and may thus become subject to disorders which temporarily or permanently destroy their powers. In these cases, then, the functional activity determines the increased supply of blood, and occasions the augmented growth; and increased nutrition will rarely take-place in these tissues without an especial stimulus of this kind. Thus we find that, when a larger supply of nutritive matter is introduced into the circulation than is required to repair the waste of these tissues, they do not undergo an increased development in consequence; but if the excess be not adequately eliminated from the system, its accumulation in the body gives rise to various forms of disease.

621. In the healthy condition of the organism, the Nutrition of every part of the body goes-on in a degree sufficient to keep it constantly ready for the performance of its appropriate function: a regular supply of the requisite materials being furnished in the aliment, and being prepared by the assimilating processes; whilst the products of the waste or decay of the tissues, together with such alimentary materials as may be superfluous, are carried off by the Excreting operations. When the nutrition and the waste are equal, the weight of the body remains the same; and this is commonly the case in adult age. But during the earlier

periods of life, the powers of growth are greater; the demand for food is very large in proportion to the bulk of the body; and though the waste is rapid, and the excreting processes very active (as evinced by the large amount of urea and of carbonic acid set free), the growth predominates over the decay, and the development of the whole structure proceeds at a gradually-increasing rate, until the full stature and bulk are attained. The energy of the nutritive process is then particularly manifested in the rapidity and completeness with which severe injuries occasioned by disease or accident are repaired. In advanced life, on the contrary, although the waste is comparatively small, the renewing processes are enfeebled in a still greater degree; and there is a gradual diminution in the stature and bulk of the body, and in its physical powers. All the functions are performed with decreased energy: and the comparative inertness of the nutritive processes is seen in the difficulty with which the effects of severe injuries are repaired, as shown in the length of time requisite for the purpose, and frequently in the imperfection of the result.

622. During the successive periods of life, there are many remarkable changes in the relative Nutrition of different organs, which we can attribute to nothing else than to inherent differences in their own powers of development. Thus, during the early stages of fœtal existence, the greatest energy of growth is seen in certain parts which are to answer but a temporary purpose, and which are afterwards completely atrophied. This is the case, for example, with the Corpora Wolffiana, which seem to answer the purpose of temporary kidneys, and in connection with which the permanent kidneys and the genital organs are developed; and of these bodies, though of large size in the early embryo, and evidently of great importance, no trace whatever is afterwards to be discovered. So in regard to the Supra-Renal capsules, the Thymus and Thyroid glands, and other organs, we find their proportional size the greatest, and their function evidently the most active, during fœtal existence and in early infancy; after which their bulk diminishes in proportion to the rest of the body, and their functional activity seems almost at an end.

623. Even in the relative development of the organs which form essential parts of the permanent structure, we find considerable variations at different periods of life. Thus the evolution of the Generative system does not usually take-place until the rest of the body is approaching its maturity; though cases sometimes occur in which this apparatus attains its full development, both in the male and in the female, at a very early period of childhood, and seems capable of performing its functions. In the Human species, these organs when once evolved remain always in a state of preparation for the performance of their function, unless they are atrophied through complete disuse,

or have lost their vigour through age or excessive demands upon their activity: but in most of the lower animals, the development of these organs is periodical through the whole of life, taking place at a certain season of the year, and being greatly influenced (it would appear) by the external temperature and by the supply of food. Thus in the Sparrow, the testes are no larger than mustard-seeds during the greater part of the year; but in the spring, they acquire the size of large peas, and it is then only that they possess any procreative power.

624. We are not always to judge of the degree of development of organs, however, by their *size* alone; for the completeness of their structure, and their aptitude for the performance of their functions, must also be taken into the account. Thus, in the new-born infant, the organs of Digestion and Assimilation, though of small size, are so completely formed as to be able at once to take-on the duty of receiving and preparing the nutritive materials, provided these are supplied in a form adapted to their powers; the Circulating apparatus is fully adequate to transmit the products of the action of those organs to the body in general, and to bring-back the results of its continual decay; and the Respiratory organs, together with other parts of the Excretory apparatus, are so completely evolved, as to be able to separate the effete matter, and to cast it out of the system, with an energy equivalent to that of the organs by which new matter is introduced and appropriated. On the other hand, the Brain, although of larger comparative *size* at birth than at any subsequent period of life, is but very imperfectly developed; for its structure is not yet so far completed as to prepare it for a state of high functional activity. In fact, it would seem as if the use of the organ, called-forth by the new circumstances in which the infant is placed as soon as it comes into the world, is essential to its complete development; and the same may be said of the Muscular system.

625. During the whole period of infancy and childhood, the current of Nutrition seems peculiarly directed towards the Brain; for though its *size* does not continue to increase in proportion to that of the remainder of the body, its *structure* is evidently being rendered more perfect, and its functional activity is excited with remarkable facility. Hence it is peculiarly liable to be acted-on by various causes which may produce disease; and the operation of remedies which specially affect that organ is far more powerful than at any other period of life. Thus, whilst a child will bear a fourth, or even a third, of the dose of a purgative adequate for an adult, it is strongly affected by an eighth or even a twelfth of the dose of a narcotic or stimulant that would be required to produce a corresponding effect in middle life. This peculiar impressibility of the nervous system, resulting from the activity of the

nutrient processes which are taking-place in it, manifests itself also in other ways; thus children are peculiarly liable to have their powers depressed by any sudden shock, such as a blow, or an extensive burn or laceration; whilst, on the other hand, if the depression be not fatal, they recover from its effects much more speedily than an adult would do from a similar condition.

626. During the periods of youth and adolescence, the chief energy of Development (except in regard to the generative system already noticed) appears to be directed towards the Muscular apparatus, which then increases in vigour in a degree that surpasses its increase of size; and the circulating and respiratory organs, upon whose energetic action there is then a corresponding demand, are peculiarly liable to disturbance of function, inducing disease in themselves or in other parts. The maladies of this period are for the most part of a *sthenic* or *inflammatory* character; resulting from the excessive activity of the assimilating processes, which are disposed to produce more plasma than the wants of the body require. Or if, on the other hand, there be an imperfect elaboration of the nutrient materials, as happens in the *tubercular* diathesis, its effects are peculiarly liable to manifest themselves at this period, when the demand for nutritive matter is greatly augmented by the activity of the muscular system.

627. In adult age, there should be such a balance of all the functions, arising from the due development and proper use of each organ, as may preserve the body in the state of health and vigour, without any marked change in the relative dimensions of its different parts, through a long series of years. The digestive, assimilating, and excreting organs, as they were the first to come to maturity, are commonly the first to fail in their activity; but this is very generally the result of over-exertion of their powers, the amount of food introduced into the stomach being rarely (among the higher and middle classes of society at least) kept down to the real wants of the system. The muscular apparatus usually experiences the effects of this diminished nutrition sooner than the nervous system; the vigour of the latter being often sustained in a remarkable degree (as is shown by the energy of the mental operations) through a protracted life, when it has not been over-tasked at an earlier period. The very slight impairment of the nutrition of the Nervous System, during the general emaciation which results from a wasting disease, or during that more gradual decline of the bodily vigour which is consequent upon advancing age, is a phenomenon which strongly marks it out as the part of the body to the maintenance of whose integrity everything else is subservient; and this is still more strikingly shown in the phenomena of Starvation, in which state, notwithstanding the disappearance of the whole of the fat, and the reduction of the weight of the body in general by about 40 per cent., the nervous system appears to lose little or none of its substance (§ 117).

3. *Of Death, or Cessation of Nutrition.*

628. The general cessation of the Nutritive operations in *Death*, usually depends, as formerly explained (§ 64), upon the cessation of the supply of Nutriment, in consequence of the stagnation of the Circulating current; and this stagnation may result from the *direct* operation of three causes; namely,—failure in the propulsive power of the Heart, or *Syncope* (§ 581),—obstruction to the flow of blood through the pulmonary capillaries, consequent upon a deficient supply of air, or *Asphyxia* (§ 706),—and a perverted state of the blood itself (such as is produced by the introduction of a powerful septic poison), which at the same time weakens the power of the heart, and prevents the performance of those changes in the systemic capillaries which afford a powerful auxiliary to the circulation; a mode of death for which the term *Necræmia* has been proposed. Each of these conditions may be dependent upon a variety of remote causes, which cannot be here particularized. But it is evident that, when either one of them has been established, the nutritive processes must speedily cease, although they may continue for a short time at the expense of the blood in the capillaries of the part. The cooling of the body is another cause of their cessation; and this is one reason why *molecular* death (or the death of the individual organs and tissues) follows so much more closely on *somatic* death (or the cessation of the circulating and respiratory functions) in warm-blooded than in cold-blooded animals. In either case, however, the solid tissues may preserve for a time their independent vitality; and changes may take-place in them, which indicate the continuance of their nutritive actions to a certain extent, even when they have been entirely disconnected from the body.—There are undoubtedly cases, however, in which the loss of vital power is as complete and immediate in the solids as in the fluids; the want of ability to avail themselves of nutriment being as decided in the former, as the deficiency of supply is in the latter. This is seen, for example, when death results from a sudden and violent shock, which destroys the vitality of the whole system alike (§ 603); molecular death being here consentaneous with somatic. And in some of the pernicious Fevers of the African coast, the body seems to die gradually from the extremities towards the centre, the limbs becoming gangrenous before the Heart ceases to beat.

629. But as each component part of the Animal fabric has an individual *life* of its own, so must it have a *limited duration* of its own; the *period of termination* of its vital activity, or its *death*, being quite independent of that of the body at large, excepting in so far as the operations of the latter are requisite to afford it a

constant supply of appropriate nutriment, and to maintain its temperature at the proper elevation. It is perfectly compatible, on the other hand, with the Life of the entire organism, that certain parts of it should be continually in course of decay and renewal; and, in fact, we find that the most important parts in the vital functions are performed by tissues whose individual duration is comparatively brief, but which are renewed as fast as they degenerate. We have a well-marked example of this in the case of the leaves of trees, which are the chief agents in the preparation of the nutritious fluid at whose expense the permanent tissues of the trunk and branches are developed; and although there is nothing in the Animal body at all comparable to the complete exuviation which commonly takes-place in the Plant at the close of the season of vegetative activity, yet there is a continual death and separation of parts that have performed their function, which in the end makes-up a much larger aggregate. Thus there is scarcely a less complete renewal of the epidermis in Man, in the course of twelve months, than there is in Serpents, Frogs, &c., which throw it off periodically; the only difference being, that in the one case the whole is exuviated and renewed at once, whilst in the other there is a continual interchange. In the exuviation of the antlers of the Deer and of the milk-teeth of all Mammalia, we have very marked examples of this limitation of the life of individual parts even in the highest Animals; and, as a general proposition, it may be stated that every part must degenerate when it has gone through the whole series of changes in which its Life consists, and that it must then either die and decay, or must be so altered in its constitution as to be able to remain inactive without further change.

630. Hence we see that the duration of vital activity must be *cæteris paribus* in the inverse ratio of its energy; that is, the life of any part, or of the entire organism, must be shortened by any excess of functional activity; whilst it may be prolonged by such a degree of repose, as does not involve an impairment of its nutrition. We see this most remarkably exemplified in the case of Cold-blooded animals; the duration of whose life, after they have sustained some fatal injury (such as the removal of the heart or of the lungs), or are placed in any other circumstances incompatible with its continuance, is in the inverse proportion to the elevation of the temperature to which they are exposed, and therefore to the degree of their vital activity (§ 128). Now although, in consequence of the comparative uniformity of the temperature of Warm-blooded animals, such variation is comparatively little observable in the rate of life of that portion of their fabric which is concerned in their organic functions, it is clearly seen in those organs whose functional activity is more under the control of the individual, and is therefore less constant. Thus, in Man, we

continually notice that the duration of the powers of the Brain and of the Generative system is the longest when these organs have been moderately exercised, and that it is much curtailed by the excessive use of either. The duration of their activity, however, is not increased by partial or entire disuse of the organs; for this induces a state of Atrophy, on the principles already mentioned. Now we have every reason to believe that what is true of individual parts and organs, is true also of the whole structure; and that the existence of the entire bodily fabric may thus come to an end without any special disease, in consequence of the limit originally set to its powers of self-renovation. It is but rarely, however, that this occurs; the various accidents of life, the neglect of ordinary precautions for the preservation of health, and hereditary tendencies to various kinds of morbid action, being too frequently the means of cutting-off the term of Human existence long before its natural expiration.

4. *General Balance of the Vital Economy.*

631. The elaborate researches which have been recently carried out by various experimenters, unto the relations which subsist between the *Ingesta*, the *Metamorphosis of Tissue*, and the *Egesta*, have made important additions to our knowledge on this subject, though many points still remain open to investigation.—In the first place it may be laid-down that an animal entirely deprived of food lives (so to speak) upon its own tissues. We have seen (§ 117) that one principal demand—that for calorifying material—is then partly supplied by the consumption of the store of Adipose matter previously laid-up; and the duration of life under such circumstances mainly depends upon the amount which the body can thus furnish, the fattest animals being those which can longest sustain total deprivation of food. But a gradual wasting also takes-place in nearly every portion of the fabric; so that when death at last supervenes, the Nervous system appears to be the only part which has not experienced a serious diminution of substance. In his experiments on Pigeons, M. Chossat found that the total average loss was about 40 per cent.; and he thus tabulates the loss sustained by different organs:—

Parts which lose *more* than 40 per cent.		Parts which lose *less* than 40 per cent.	
Fat	93·3	Muscular coat of Stomach	39·7
Blood..	75·0	Pharynx and Œsophagus	34·2
Spleen	71·4	Skin	33·3
Pancreas	64·1	Kidneys	31·9
Liver	52·0	Respiratory Apparatus	22·2
Heart	44·8	Osseous system ..	16·7
Intestines	42·4	Eyes	10·0
Muscles of Locomotion	42·3	Nervous system ..	1·9

We see, from this table, that whilst the Fat is almost entirely removed, and the Blood is reduced to one-fourth of its usual amount, the Organs that suffer most are those concerned in the Assimilation of nutriment, which process is entirely suspended; the Muscles of Organic and of Animal life lose nearly the same proportion of their weight, and this loss closely accords with the average loss of the whole body; the Kidneys and Respiratory apparatus, whose functional activity is but slightly diminished, show a much smaller reduction; the Bones lose about a sixth, which seems a large proportion when the comparative permanence of their substance is considered; but the most remarkable phenomenon of all is the insignificant loss exhibited by the Nervous system, which would seem to maintain itself at the expense of all the available supply of nutritive substance, until the exhaustion of the heat-producing materials occasions a reduction in the temperature of the body which is incompatible with the persistence of its vital activity (§ 118).

632. From an examination of the Excretions of a Cat which was kept without food for 18 days, and died at the end of that time, having lost half its weight, it was ascertained by MM. Bidder and Schmidt that the diminution in weight was equal for equal periods, except during the first few days, when it was somewhat greater in consequence of the excretion of the remains of the previously-ingested food. The quantity of Carbonic acid expired at first steadily fell with the diminishing weight of the body, so that during this period its *proportional* amount remained the same; it then increased from the 8th to the 16th day, so as to be rather above the normal proportion as compared with the weight of the body; and during the last two days it underwent a rapid diminution, the temperature of the body falling in like proportion, as in the experiments of Chossat (§ 117). From a comparison of the quantity of Nitrogen eliminated by the Urine with that of the Carbon eliminated by the Lungs and Skin, it was ascertained that the daily quantity of Fat undergoing oxidation remained nearly constant up to the almost total exhaustion of the supply; and that the variations in the exhaustion of Carbonic acid depended rather upon differences in the rate of metamorphosis of the Albuminous components of the body. This metamorphosis fell during the first two days to one-half the normal amount, but then remained constant for eight days, then fell slowly, and during the last two days diminished rapidly and considerably. Thus in the earlier period of the fast, the maintenance of the temperature was partly provided-for by the metamorphosis of the Albuminous compounds, as well as by the oxidation of the Fat; but during the later stage it depended almost exclusively on the latter; and hence it was that the temperature fell so rapidly when the Fat was nearly exhausted. On

the whole, it was found that the animal lost daily 1 per cent. of its body-substance, calculated as *free from water;* and that of this loss, *three-fifths* consisted of Albuminous substances, and *two-fifths* of Fat. The former, it seems probable, are chiefly consumed in that *opus vitale* (§ 639) which even a starving animal must perform.—The terminal products of the materials of these substances, eliminated daily in combination with the Oxygen taken-in from the atmosphere, and including the Water normally accompanying them, were as follows:—

2·16	per cent. of the body weight of		Carbonic Acid	By the Skin and Lungs.
1·60	,,	,,	Aqueous Vapour	
0·20	,,	,,	Urea	By the Kidneys.
0·008	,,	,,	Sulphuric Acid	
0·011	,,	,,	Phosphoric Acid	
0·029	,,	,,	Salts	
0·08	,,	,,	Dry Fæces, including 0·62 per cent. of biliary matters.	
2·24	,,	,,	Water	By the Urine and Fæces.

It is remarkable, as showing the great importance of Chloride of Sodium in the animal economy, and the tenacity with which it is retained by the tissues, that this salt soon entirely ceased to be excreted.

633. Now it has been clearly ascertained by the experiments of MM. Bidder and Schmidt, that the amount of the loss thus sustained by an animal entirely deprived of food, is far from affording the measure of the aliment required for the proper maintenance of the organism; for they found that whilst the weight of an inanitiated Carnivorous animal diminished about 2·2 per cent. daily, the quantity of food required to keep up its weight to the ordinary standard is *nearly twice as great.* Thus it appears, that a 'retrograde metamorphosis' of the components either of the food or of the organism must take-place daily, to nearly half the amount of the food ingested, in order that the new material required to repair the 'waste' of the system may be appropriated by its textures. Of this remarkable fact, we seem to have a partial explanation in the large amount of Secretory products required for the first reduction of the aliment to a state that enables it to be absorbed: thus, according to the estimate of MM. Bidder and Schmidt, the aggregate amount of solid matter contained in the secretions daily poured into the alimentary canal of an adult Man weighing 14 stone, is not less than 4,772 grains; so that nearly 10 oz. (troy) of solid matter are separated from the

blood in the digestive process alone, to supply the means of introducing an amount of new alimentary material not more than two or three times as great. But further, in that act of Assimilation, which seems to be the special function of the Vascular Glands and of the Absorbent system, there is evidence of *retrograde* concurrently with *progressive* metamorphosis (§ 635); as if the descent of one portion of the complex organic compounds to simpler states of combination were a necessary condition (as it seems to be elsewhere, § 411) of the *elevation* of another portion to a state that enables them to be appropriated by the Tissues.

634. From the observations of MM. Bidder and Schmidt upon the excretions of a Cat which was allowed for a week as much meat as it could eat, it appears that 100 parts of dry flesh are decomposed in the living body, with the co-operation of 167 parts of oxygen obtained from the atmosphere, into 31 parts of urinary products, 2 parts of fæcal matter, 182 parts of carbonic acid, and 52 parts of aqueous vapour. Now since nearly the same relative proportions obtain, when the animal, being deprived of nutriment, is living upon its own tissues, we may regard them as representing the mode of ultimate metamorphosis of Albuminous matter, whether furnished by the tissues of the animal, or by the food which it has ingested; and thus it appears that, with the exception of a very small amount of fæcal matter, all the products of this metamorphosis are eliminated by the Lungs, Skin, and Kidneys. On the fæcal matter, moreover, nearly the whole consists (in a purely Carnivorous animal) of Earthy salts; the only other constituent of importance being Sulphur,—about half of that which is taken-in as a constituent of the food being eliminated in an unoxidized form through this channel, while the other half undergoes oxidation and passes off by the urine in the form of an alkaline sulphate.—From the above and other data, the following table has been constructed by Dr. Dalton* of the ordinary balance between the daily *ingesta* and *egesta* of an adult Man weighing 140 lbs.:—

Introduced during 24 *hours.*	lbs.	*Discharged during* 24 *hours.*	lbs.
Oxygen	1·019	Carbonic Acid ..	1·535
Water	4·735	Aqueous Vapour ..	1·155
Albuminous matter ..	·396	Perspiration	1·930
Starch	·660	Water of Urine ..	2·020
Fat	·220	Urea and Salts ..	0·110
Salts	·040	Fæces	0·320
	7·070		7·070

* "Human Physiology," 3rd Ed., p. 363.

635. Although the successive steps of the retrograde metamorphosis of the Albuminous compounds have not yet been fully made out, there seems no room to doubt that these compounds resolve themselves into two groups of substances, of which one series includes the whole of the Nitrogen, whilst the other consists of C, H, O, alone. Mention has already been made (§ 195) of two substances, *Leucin* and *Glycin* which can be obtained by artificial means both from Albuminous and from Gelatinous compounds; and these, with another allied substance *Tyrosin* (also capable of being artificially produced), can be obtained from various tissues in the body; being most abundant in those organs in which Assimilating changes are most rapidly going-on, as the Spleen and Liver. Glycin enters into the composition of the glycocholic acid of the Bile; and may also be obtained from the hippuric acid which enters largely into the composition of the Urine of Herbivorous animals. The further decomposition of Leucin by artificial means yields certain volatile fatty acids and ammonia, which have been ascertained to occur in glandular organs and in the blood. Hence there can be little doubt that one form of retrograde metamorphosis of Albuminous and Gelatinous compounds goes-on along the line (so to speak) which has been thus traced out in the laboratory of the Chemist.

636. There is another form of metamorphosis, however, which probably takes place to a much greater amount; that, namely, of which we have evidence in the presence of various compounds that are more or less closely related to the principal constituents of the Urinary excretion, in the 'extractive' of Muscles that have been subjected to active exertion (§ 338). We do not, it is true, find either Urea or Uric acid in this 'extractive'; but both kreatin and kreatinin are readily convertible into Urea; and the relation of Inosinic acid both to Urea and to Uric acid is very intimate.

637. On the other hand we have seen (§ 172) that there is evidence that *Hepatin* may be formed in the Liver at the expense of Albuminous substances; and this would seem to be the product which ordinarily forms the complement (so to speak) of the highly-azotized matters already spoken of. For whilst these are taken back from the muscles and other organs in which they are generated, into the current of the circulation, and are thus conveyed to the Kidneys by which they are eliminated, the complementary non-azotized matter, separated in the form of Glycogen in the Liver, seems usually to be received back into the blood-current, and to undergo a further change into Glycose (§ 187) which, in passing through the Lungs is finally converted by oxidation into Water and Carbonic acid.—But it would also appear that if the hydrocarbonaceous matter left by the separation of the azotized constituents should be in excess of the amount which the oxidizing process is ready to carry off, it may be deposited in the

tissues as Fat. Thus an animal may be fattened upon flesh alone; but this will only be at the expense of an enormous consumption of it; since, as already shown (§ 439), a much larger proportion than is needed to supply the 'waste' of the nitrogenous tissues, must be ingested to furnish even the ordinary amount of hydro-carbon for the respiratory process.

638. The question has of late been much discussed, whether the Urea and other highly-azotized compounds eliminated by the Urine are derived solely from the retrograde metamorphosis of the Albuminous and Gelatigenous *tissues;* or whether they may be in part the resultants of a similar degradation of a portion of the Albuminous or Gelatinous components of the *food*, which have undergone this metamorphosis without passing through the intermediate condition of organized tissue. That such a direct degradation may take place, when the proportion of azotized matter in the aliment is greater than is required to supply the wants of the system, was long since maintained by the Author, as a justifiable inference from the well-known fact that the production of Muscular tissue is not augmented by excess of its material in the blood, but by the demand created by its use (§ 360). Such excess, therefore, cannot be got rid of in any other way than by retrograde metamorphosis; that is, by the resolution of the superfluous matter into such products as the Excretory organs are fitted to draw-off. And the general tendency of recent analytical investigations has been decidedly to favour this view; by showing that the ordinary elimination of Urea in *well-fed* men or animals bears a much more close and constant relation to the amount of Azotized material taken-in as food, than it does to the amount of muscular exertion put forth; and that in various Pathological states there is almost certain evidence of the disintegration of Albumen without its being applied to the formation of tissue. If an animal be *under*-fed with Albuminous matter, *all* that matter will probably be applied to the nutrition of its tissues; and the quantity of Urea, &c., that appears in the urine will be the measure of their disintegration, which will be in excess of the food supplied, the body undergoing an equivalent reduction in weight. If it be *adequately* fed with Albuminous matter, all that matter will still be applied to the nutrition of its tissues; and the quantity of Urea, &c., in the Urine will still represent the amount of their disintegration: but if the weight of the body be sustained without increase or diminution, it will also represent the amount of azotized food ingested. If, again, an animal be *over*-fed with Albuminous matter, only a part of that matter will be applied to the nutrition of its tissues; and the quantity of Urea, &c., in the Urine will be augmented by the direct resolution of the excess into the azotized and the hydro-carbonaceous Excretory products. This principle is of great importance in the

treatment of those states of the system in which there is an excess of azotized matters in the urine, and especially when that excess takes the form of Uric acid (§ 733).

639. When, however, the Azotized materials of the Food and the Waste of the Azotized tissues are duly balanced, the amount of Urea excreted may be regarded as the exponent of the *work* done; and the results of the recent enquiries of Prof. Haughton seem to justify a distinction between (1) the *opus vitale*, (2) the *opus mechanicum*, and (3) the *opus mentale*. The first of these divisions includes all the actions, such as those of the Heart and Respiratory muscles, which are essential to the maintenance of life: as the performance of these is constant, the waste they involve is equally constant; and this seems to be represented by about 2 grs. of Urea per diem for each pound of body-weight, so that in a Man of 140 lbs. weight, the amount of Urea thus generated will be 280 grains daily. Where neither bodily nor mental labour is performed, the amount excreted may normally fall to this quantity; but it cannot be reduced below it without a retention of excretory products in the system, giving rise to the state called Uræmia (§ 741). The 'opus mechanicum' of men employed only in routine manual labour, expresses itself in a production of Urea amounting to from 100 to 140 grains daily. The 'opus mentale' seems to involve a much more considerable waste; the quantity of Urea produced during five hours of close study, or eight hours of office-work, rising to as much as 220 grains. This result is in accordance with general experience; which shows that men employed in ordinary manual labour which does not task the mental powers, can maintain their bodily vigour on a diet mainly consisting of bread and vegetables; but that sustained intellectual labour requires a diet containing a larger proportion of highly-azotized nutriment.

640. Notwithstanding the very numerous experiments which have been made to determine the influence of various articles in common use among mankind,—such as Alcohol, Tea, Coffee, Tobacco, &c.—upon the general course of the nutritive operations, as manifested in the proportion between the *Ingesta* and the *Excreta*, it cannot be said that any satisfactory conclusions have yet been attained. It has been maintained that these articles have the power of checking or diminishing the 'waste' of the tissues; and they have hence received the title of 'arresters of metamorphosis.' But all we at present know of the conditions of vital activity, leads to the conclusion that neither *opus mechanicum* nor *opus mentale* can be performed without an equivalent amount of metamorphosis either of tissue or of materials for tissue; and it is not easy to see how that *opus vitale* which is essential to the maintenance of Animal life can go on, if its equivalent of metamorphosis be reduced. Moreover, the conclusions

drawn from the experiments alluded to are open to the objection that the results on which they are based are too limited in duration to be of any real value; for the enquiries of Dr. Edward Smith have shown that the effect of almost any departure from the ordinary regimen (as the addition or subtraction of one of the substances named above) is shown in a marked disturbance *for a few days* in the proportions of the Excretory products; but that if the principal constituents of the diet and the amount of work done remain the same, the ordinary proportions are soon restored. —Nevertheless the common experience of Mankind seems to show that, when the supply of Food is *less* than the wants of the system require, the use of Alcohol in small quantities, of Tea, Coffee, or Tobacco, makes that food go further; and the craving for one or other of these articles, which shows itself most strongly among ill-fed populations, or under circumstances of extreme privation, appears to indicate that they exert some decided effect upon the system.

CHAPTER IX.

OF RESPIRATION.

1. *Essential Nature and Conditions of the Respiratory Process.*

641. The function of Respiration essentially consists in an interchange of Oxygen and Carbonic acid between the blood and the surrounding medium; carbonic acid being given-out by the blood, and oxygen entering in its stead. It has been already noticed (§ 84) that this function is performed likewise by Plants; although, in consequence of their deriving a large part of their Food from the atmosphere by a converse process (the absorption of carbon and the liberation of oxygen) their true Respiration is commonly overlooked. It may, therefore, be regarded as common to all Organized beings.—Every one is conscious, in his own person, of the imperative demand for the due performance of this operation. If the breath be purposely held for even a few seconds, a feeling of discomfort is experienced, which increases every moment, and at last prompts irresistibly to the respiratory movement. And if the admission of air to the lungs be in any way prevented, the respiratory movements are at first increased in energy, violent efforts being made to obtain the needed supply; these are succeeded by irregular convulsive actions, insensibility coming on simultaneously; and within a short time all movement ceases, the circulation of the blood is suspended, and a stop

is put to all the vital operations of the body. This state, which is termed *Asphyxia*, is usually complete, in a warm-blooded animal, within ten minutes of the time when the respiration is wholly checked; thus affording the most convincing proof of the importance of that function in the Animal economy. In many cold-blooded tribes, however, a much longer suspension may be borne with impunity; as also by warm-blooded animals when the general activity of their functions is lowered in the state of *hybernation* (§ 121).—We shall now inquire into the sources of the necessity for this interchange of Oxygen and Carbonic acid; and the mode in which the suspension of it acts upon the system at large.

642. All Organized bodies, as already explained, are liable to continual decay, even whilst they are most actively engaged in performing the actions of Life; and one of the chief products of that decay is carbonic acid. A large quantity of this gas is set free during the decomposition of almost every kind of organized matter; the carbon of the substance being united with oxygen supplied by the air. Hence we find that the formation and liberation of carbonic acid goes-on with great rapidity after death, both in the Plant and in the Animal; and that it takes-place also, to a very great extent, in the period that often precedes the death of the body, during which a general decomposition of the tissues is occurring. Thus when Plants become unhealthy, the extrication of carbon in the form of carbonic acid exceeds in amount its fixation from the carbonic acid of the atmosphere; and the same change normally takes-place during the period that immediately precedes the annual fall of the leaves, their tissue being no longer able to perform its proper functions, and giving-rise by its incipient decay to a large increase in the quantity of carbonic acid set free. The same thing probably happens in the Animal body, during the progress of many diseases which are attended with an extraordinary tendency to decomposition in the solids and fluids; for in such cases the blood commonly exhibits an unusually dark hue, indicating that it has not been properly freed from the excessive amount of the carbonic acid which it has received from the tissues. It has not yet been accurately determined, however, whether there is an increase in the amount of carbonic acid actually thrown-off in such cases.

643. Hence the first object of the Respiratory process, being that which is common to all forms of Organized being, is to extricate from the body the Carbonic acid which is one of the products of the continual decomposition of its tissues. The softness of many of the tissues of Animals, and the large quantity of fluid contained in their bodies, render them more prone than Plants to this kind of decomposition; and in warm-blooded animals, the high temperature at which the fabric is usually

maintained, adds considerably to the degree of this tendency; so that the *waste* of their tissues, from this cause alone, is much greater than that of Plants. But when the temperature of the Reptile is raised by external heat to the level of that of the Mammal, its need for Respiration increases, owing to the augmented waste of its tissues. When, on the other hand, the warm-blooded Mammal is reduced in the state of hybernation to the level of the cold-blooded Reptile, the waste of its tissues diminishes to such an extent as to require but a very small exertion of the respiratory process to get-rid of the carbonic acid which is one of its chief products. And in those animals which are capable of retaining their vitality when frozen (§ 136), or when their tissues are completely dried-up (§ 159), the decomposition is for the time entirely suspended, and consequently there is no carbonic acid to be set-free.

644. But another source of Carbonic acid to be set-free by the Respiratory process, and one which is peculiar to Animals, consists in the rapid changes which take-place in the Muscular and Nervous tissues, during the period of their activity. It has been already shown (§ 338) that there is strong reason to believe that a waste or decomposition of Muscular tissue takes-place with every exertion of it; moreover, we have seen the presence of Oxygen to be essential to the continued development of muscular force; and one of the products of the union of oxygen with the elements of muscular fibre is Carbonic acid (§ 536). The same is doubtless true of the Nervous tissue. Hence it may be stated as a general principle, that the peculiar 'waste' of the Muscular and Nervous substances, which is a condition of their functional activity, and which is altogether distinct from the general slow decay that is common to these tissues with others, is another source of the Carbonic acid which is set-free from the animal body; and that the amount thus generated will consequently depend upon the degree in which these tissues are exercised. In animals which are chiefly made-up of the organs of Vegetative life, in whose bodies the nervous and muscular tissues form but a very small part, and in whose tranquil plant-like existence there is but little demand upon the exercise of these structures, the quantity of carbonic acid thus liberated will be extremely small. On the other hand, in animals whose bodies are chiefly composed of muscle, and whose life is an almost ceaseless round of exertion, the quantity of carbonic acid thus liberated is very considerable.

645. Recent enquiries, however, have rendered it doubtful whether the whole amount of Nervo-muscular force put-forth by an Animal can be accounted-for by the oxygenation of the elements of its tissues; and whether Food may not be applied to the development of Energy, as it undoubtedly is to the production of Heat, without passing through the condition of Organized

structure. The facts at present known do not justify a positive conclusion upon this point; but they indicate unmistakeably a very close and constant relation to exist (other conditions remaining the same) between the amount of force generated and the amount of Carbonic acid evolved. Of this relation we find most remarkable examples in the class of Insects. They have no fixed temperature to maintain, and they are consequently not in the condition of warm-blooded animals, in which the quantity of carbonic acid set-free is kept-up to a more regular standard by the provision to be presently noticed: on the other hand, they are pre-eminent among all Animals in regard to the energy of their muscular power in relation to the bulk of their bodies. Now a Humble Bee has been found to produce one-third of a cubic inch of carbonic acid in the course of a single hour, during which its whole body was in a state of continual agitation from the excitement consequent upon its capture; and yet during the whole twenty-four hours of the succeeding day, which it passed in a state of comparative rest, the quantity of carbonic acid generated by it was absolutely less.

646. Besides these sources of Carbonic acid, which are common to all animals, there is another which appears to be peculiar to the two highest classes, Birds and Mammals. These are capable of maintaining a constantly-elevated temperature, so long as they are supplied with a proper amount of appropriate food; and their power of doing so appears to depend upon the *direct* combination of certain elements of the food with the oxygen of the air, by a process analogous to combustion; these elements having been introduced into the blood for that purpose, but not having formed a part of any of the solid tissues of the body, unless they have been deposited in the form of fat. The nature of these substances has been already noticed (§ 431). They can only be applied in a very limited degree to the nutrition of the tissues that originate in albuminous compounds; and although they may be for a time removed from the circulating current by the agency of the Liver, yet in one mode or another they are almost wholly received into it again, and are finally thrown-off by the respiratory process.

647. The quantity of Carbonic acid that is generated directly from the elements of the food, seems to vary considerably in different animals, and in different states of the same individual. In the Carnivorous tribes which spend the greater part of their time in a state of activity, it is probable that the quantity which is generated by the waste or metamorphosis of the tissues is sufficient for the maintenance of the required temperature, and that little or none of the carbonic acid set-free in respiration is derived from the direct combustion of the materials of the food. But in Herbivorous animals of comparatively inert habits, the amount of metamorphosis of tissue is far from being sufficient; and a

large part of their food, consisting as it does of substances that cannot be applied to the nutrition of the tissues, is made to enter into direct combination with the oxygen of the air, and thus compensates for the deficiency. In Man and other animals which can sustain considerable variations of climate, and can adapt themselves to a great diversity of habits, the quantity of carbonic acid formed by the direct combination of the elements of the food with the oxygen of the air, will differ extremely under different circumstances. It will serve as the *complement* of that which is formed in other ways; so that it will diminish with the increase, and will increase with the diminution, of muscular activity. On the other hand, it will vary in accordance with the external temperature; increasing with its depression, as much more heat must then be generated; and diminishing with its elevation.—In all cases, if a sufficient supply of food be not furnished, the store of fat is drawn-upon; and if this be exhausted, the animal dies of cold (§ 117).

648. To recapitulate, then, the sources of Carbonic acid in the Animal body are threefold.—1. The continual decay of the tissues, which is common to all organized bodies, which is diminished by cold and dryness and increased by warmth and moisture, which takes-place with increased rapidity at the approach of death, whether this affect the body at large or only an individual part, and which goes-on unchecked when the actions of nutrition have ceased altogether:—2. The metamorphosis which is peculiar to the Nervous and Muscular tissues, which is the very condition of their activity, and which, therefore, bears a direct relation to the degree in which they are exerted:—3. The direct conversion of the carbon of the food into carbonic acid, which is needed in warm-blooded animals for the generation of Heat, and which may likewise be applied to the production of motor force.

649. Now the function of Respiration has for its object, not merely to extricate the Carbonic acid which is generated in the system, but likewise to introduce the Oxygen which is required for the formation of that carbonic acid, as well as for other purposes. Hence it is not enough that the carbonic acid should be removed; for this may be accomplished by causing an animal to breathe an atmosphere which contains no oxygen. Any cold-blooded animal, such as a Frog or a Snail, may be kept in hydrogen or nitrogen for several hours or even days; and will give-out, during that time, an amount of carbonic acid nearly as great as if it had been respiring atmospheric air. But the continued production of carbonic acid must have a limit, occasioned by the want of oxygen; and death will then supervene.—On the other hand, a supply of oxygen may be freely afforded; and yet the presence of even a small amount of carbonic acid in the surrounding atmosphere (in addition to that which is normally present in

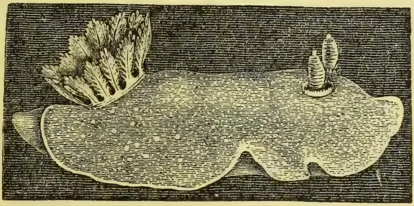
it, § 81) will impede the extrication of that substance from the blood; and if the excess be considerable, the carbonic acid will not be set-free at all; so that the same injurious results follow as if respiration were altogether prevented from taking place.

650. These two changes are accomplished by the very same act, in accordance with the property of 'mutual diffusion,' which is common to all gaseous substances that do not unite chemically with one another. In virtue of this property, Hydrogen, the lightest of gases, and Carbonic acid, one of the heaviest, when introduced into the same vessel, will be found in a short time to have uniformly mixed, notwithstanding the difference of their specific gravities, which are as 1 to 22. Now this intermixture will take-place when the two gases are separated by a porous septum; each gas passing towards the other, by an action resembling the Endosmose and Exosmose of liquids (§ 491). And it may also take-place when one of the gases is diffused through a liquid, provided that the other gas is likewise capable of being absorbed by that liquid. In this manner, as already mentioned (§ 534), the surface of venous blood enclosed in a bladder will be made to exhibit the arterial hue, by suspending the bladder in an atmosphere of oxygen; for the carbonic acid of the blood and the surrounding oxygen will overcome by their mutual attraction the obstacle interposed by the bladder; and the former will be lifted out, so to speak, and will be replaced by the latter. It has been found by experiment, that the free carbonic acid diffused through blood may be more completely extricated from the liquid by exposing it to hydrogen, than by placing it under the vacuum of an air-pump; for in the latter case there is nothing to replace it, and the attraction between the gas and the liquid tends to resist the exhausting influence of the vacuum; whilst in the former, the blood receives one gas in exchange for the other, so that the whole force of the tendency to mutual diffusion is exercised in lifting-out the carbonic acid.

651. The immediate purpose of the organs of Respiration, then, —whatever may be the variety in their form,—is this; to expose the blood to the air in a state of such minute division as to present a very extended surface, a thin membrane only being interposed between them. For this purpose we find a certain organ, or set of organs, specially set-apart in all the higher animals; and this is formed by a prolongation of the general surface, either externally or internally, according to the mode in which the respiration is accomplished. Thus in Fishes and aquatic Mollusks, the blood is aërated by exposure, not directly to the atmosphere, but to the air which is dissolved in the water they inhabit; and their respiratory apparatus is formed of an extension of a particular part of the *external* surface into innumerable delicate fringe-like processes, the *gills* (Fig. 143). In Mollusks these are usually

minutely subdivided into filaments (Fig. 146), every one of which contains an afferent canal that conveys the blood from its base to its point, and an efferent canal that returns the blood from its point to its base. In Fishes, however, the gills have rather a

Fig. 143.*



lamellated form, each lamella containing a network of blood-vessels (Fig. 151); so that the amount of blood exposed to the surrounding medium at any one time is collectively very great, although the quantity contained in each gill-filament is very minute. In all the air-breathing Vertebrata, on the other hand, the blood is exposed to the atmosphere through the medium of an *internal* membranous prolongation, which is continuous with the mucous membrane lining the mouth and nostrils; this forms a pair of sacs termed *lungs*, communicating with the back of the mouth by means of a tube called the *trachea* or windpipe, through which air is freely admitted to the cavities thus formed (Fig. 154). The blood is minutely distributed on the walls of these sacs by a close network of capillary vessels (Fig. 157); and this not only on the external walls, but also on numerous partitions by which the cavities are subdivided with more or less minuteness, so as greatly to extend the vascular surface.

652. Such is the essential nature of the Respiratory apparatus: but in order that it may be carried into that vigorous operation which is required in Man and the higher animals generally, various supplementary arrangements are made for the purpose of promoting the due influence of the air upon the blood. In the first place, the capillary vessels of the respiratory surface are connected with arterial trunks, which issue immediately from the heart and thus convey a constant stream of blood from that organ; whilst they give origin to venous trunks which terminate directly in the heart and convey back to it the blood that has undergone aëration. Thus by the energetic action of the heart, and by the

* Doris Johnstoni, a Sea-Slug, showing the tuft of external gills.

force generated in the capillaries of the lungs (§ 597), a constant renewal is effected in the blood which is exposed to the air through the medium of these organs. On the other hand, the renewal of the blood would be useless unless a fresh supply of air were continually introduced, and that which had been vitiated by the loss of its oxygen and the admixture of carbonic acid were as constantly removed; and this is effected by a series of muscular movements, which are adapted for the alternate expulsion of the vitiated air from the lungs, and for the introduction of a fresh supply of pure air from the atmosphere. These movements are kept-up by a certain part of the Nervous system; but they are not dependent upon any exertion of the Will, for they continue during profound sleep, and in other states in which even consciousness is altogether suspended.

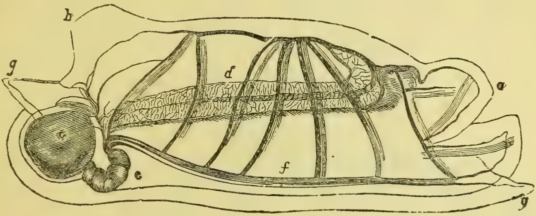
2. *Different forms of the Respiratory Apparatus in the lower Animals.*

653. Before proceeding to consider, in more detail, the structure and actions of the Respiratory apparatus in Man, we may advantageously glance at the mode in which this function is effected in the lower animals.—In the lowest and simplest, all of which are inhabitants of the water, we do not find any special apparatus for the aëration of the fluids of the body, this being accomplished by the exposure of them to the surrounding medium through the thin integument; and the interchange of the layer of water (holding air in solution) in contact with the aërating surface, is effected either by the general movements of the body, or by the action of *cilia* (§ 240) which produce the currents necessary for this purpose. Not unfrequently the internal surfaces—such as the walls of the stomach and of other cavities—seem as much concerned in this function as the external, or even more so; these cavities being distended with water taken-in through the mouth, and this water being frequently renewed by the ejection of that which has been vitiated, and by the introduction of a fresh supply. This is the case in the Sea Anemone, for example, and in many other Polypes; while in the polype-like Bryozoa there is a great dilatation of the pharynx, which seems peculiarly destined for the aëration of the fluids,—being filled with water, and then suddenly emptied, at tolerably regular intervals.

654. In the various tribes of the Molluscous sub-kingdom, we find the respiration provided-for by the adaptation of distinct organs for the purpose. As most of the animals of this group are inhabitants of the water, the respiration is usually carried-on by means of gills, rather than by any organ resembling a lung. The latter is found, however, in a few species, such as the Snail, Slug, and other terrestrial air-breathing Mollusks (Fig. 135); and

usually consists of a simple cavity, *d*, *d*, situated in the back, communicating directly with the air through an aperture in the skin, and having its walls covered with a network of vessels, or rather sinuses, through which the blood meanders.—The form and position of the gills differ extremely in the several classes of Molluscous animals. In the lowest, the respiratory surface is formed by a dilatation of the Pharynx; but sometimes, instead of surrounding a large cavity, it forms a special riband-like fold of membrane (Fig. 144, *d*) passing from one end of it to the other, on which

Fig. 144.*



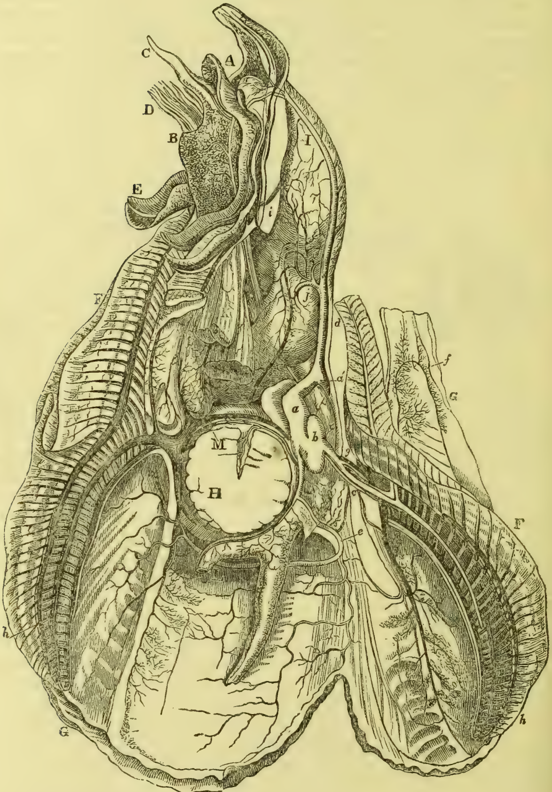
the blood is minutely distributed. In this group of animals, there is a regular system of canals for the conveyance of the blood; but these, in many parts of the system, and especially on the respiratory membrane, do not seem to be furnished with distinct walls, and are rather sinuses excavated in the tissues. And the circulation is liable to a continual change in its direction, the blood being sometimes transmitted to the respiratory surface *before* it proceeds to the body, and sometimes *after* it has traversed the other tissues (§ 557). The water in contact with the respiratory surface is continually renewed by the action of the cilia with which it is thickly covered.

655. In certain of the Mollusks inhabiting bivalve shells, we find that the inner surface of the double fold of the loose skin or 'mantle' that lines the valves, is the special organ of respiration; the external water having free access to this by the separation of the folds of the mantle along the edges of the valve. But in most Bivalve Mollusks, this surface of the mantle is doubled (as it were) into four riband-like folds (Fig. 145, F, F), which are slit into delicate fringes; to these the blood is transmitted when it

* Anatomy of Salpa:—*a*, oral orifice; *b*, vent; *c*, nucleus composed of the stomach, liver, &c.; *d*, branchial lamina, with its network of vessels; *e*, heart, from which proceeds the longitudinal trunk, *f*, sending transverse branches across the body; *g*, *g*, projections of the external tunic for union with other individuals.

has been rendered venous by traversing the vessels of the body generally; and in these it is exposed, through a surface which is

Fig. 145.*

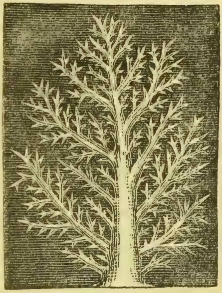


* Interior of Pinna, showing the arrangement of the Circulating and Respiratory apparatus :—A, mouth; B, foot; C, digitiform appendage to the foot; D, byssus; E, labial tentacula; F, F, branchiæ, those of the right side being in place, those of the left being divided near their anterior extremity and

greatly extended by the minute division of the fringes, to the action of water introduced from without, and constantly renewed by ciliary action. In many of these animals, as in the common Oyster, the two lobes of the mantle are so completely separated that the water can still enter freely between the valves; but in general they are more or less united, so that the cavity in which the gills lie is partially closed. In such cases free access of water from without is provided-for by means of two apertures, one for its entrance and the other for its ejection; and in certain species which burrow deeply in sand or mud, these apertures are furnished with long tubes, or *siphons*, which convey the water from nearer the entrance of the burrow, and carry it thither again. In these also, a continual flow of water over the respiratory surface is maintained by the vibration of the cilia with which they are clothed.

656. The position of the gills in Mollusks of higher organization, is extremely variable. Sometimes they are disposed upon the external surface of the body, and form delicate leaf-like or arborescent appendages (Figs. 143, 146); whilst in other cases they are enclosed in a special cavity or gill-chamber, to which water is freely admitted from without; a continual interchange being provided-for, either by ciliary action, or by muscular movements specially adapted for the purpose. The blood is conveyed to them, after having become venous in traversing the capillaries of the general system, by means of large channels and sinuses excavated in the several parts of the body (Fig. 135, *n*); and when it has been aërated in the gills, it returns to the heart, to be again conveyed to the system. In the Cuttle-fish

Fig. 146.*



turned back so as to expose their anterior surface; G, G, the mantle, of which the left lobe has been detached and folded back; H, posterior adductor muscle; I, first stomach, covered by the liver; K, retractor muscles of the foot; L, anus; M, glandular organ, probably urinary; *a*, *á*, aortic ventricle; *b*, one of the auricles turned back, the other being seen in its natural position on the opposite side of the ventricle; *c*, one of the branchio-cardiac canals; the other is seen in front of the adductor muscle H; *d*, anterior aortic trunk; *e*, posterior aortic trunk; *f*, *f*, pallial veins, proceeding to empty themselves into the branchio-cardiac canals at *g*; *h*, *h*, afferent vessels of the branchiæ; *i*, canal of communication between these last and the general lacunar system of the abdomen.

* One of the arborescent processes, forming the Gills of Doris Johnstoni, separated and enlarged.

tribe, there are supplementary hearts at the origin of the branchial arteries or vessels that distribute blood to the gills; and these have evidently for their purpose to render the respiratory circulation more energetic, and thus to increase the aëration of the blood in the degree required for the vigorous habits of these animals, which present a remarkable contrast to the sluggish inert character of Mollusks in general.—In the Molluscous classes, taken as a whole, the respiration is low in its amount. The blood contains no *red* corpuscles; and the change in its composition effected by the air would seem confined, therefore, to the fluid plasma or liquor sanguinis. And as it is not exposed directly to the air, except in a few species, but to the air contained in the water inhabited by the animals, this change cannot be very energetically performed. But as the life of these animals is chiefly vegetative,—as their movements, except in the higher classes, are few and feeble,—and as they maintain no independent heat,—there is but little need of that interchange which it is the object of the respiratory process to effect; and they can sustain the complete suspension of it for a long time.

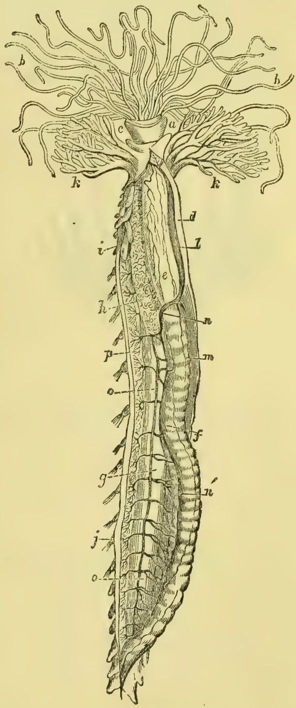
657. Among many of the Articulated tribes, the respiration is carried-on upon a similar plan. In some of the lowest, such as the Tapeworm of the intestinal canal, there is no special provision for the aëration of the fluids; the soft integument permitting the extrication of carbonic acid and imbibition of oxygen in the required degree through any part of it. This degree is but very small, however; the life of these animals being almost purely vegetative. In the Marine Worms, which constitute a numerous and interesting group, endowed with considerable locomotive power, and leading a life of almost constant activity, there is, on the other hand, a special provision for this function; the circulating fluid being transmitted in its course to a series of gill-tufts,* which are composed of a delicate membrane prolonged from the external surface of the body, and which sometimes have the form of branching trees, and sometimes of delicate brushes made-up of bundles of distinct filaments. In either case the filaments are traversed by blood-vessels, and are adapted to bring the blood into close relation with the surrounding water; and the continual interchange of the latter is provided-for by the restless movements of the body as well as by ciliary action. The tufts are sometimes arranged along every segment of the body, and their multiplication prevents them from individually attaining any considerable size: in other cases, they are disposed at intervals, and they are then larger but less numerous. Their most beautiful

* The curious double system of Circulation presenting itself in many members of this group,—not merely the *vessels* but the *fluids* respectively subservient to Nutrition and Respiration being distinct,—has already been noticed (§ 550).

development is where they are present on the head only, the rest of the body being enclosed in a shelly or sandy tube, as in the *Serpula* and *Terebella* (Fig. 147); for they then present the appearance of flowers of the most brilliant and delicate hues. In many animals of this group, there is a small supplementary heart at the base of every one of the vessels that distribute the blood to the gills; and this is obviously designed to aid in the respiratory circulation, for which the feeble action of the dorsal vessel would not furnish sufficient power.

658. The higher Articulated classes are, for the most part, adapted to atmospheric respiration according to the plan to be presently explained; but there is one class, that of *Crustacea*, whose respiration is still carried-on through the medium of water. In the lowest forms of this group there is no special respiratory apparatus; the general surface being soft enough to admit of the required aëration of the fluids through its own substance, and the animal functions being performed with so little activity that a very small amount of interchange is required. In the higher orders, however, whose bodies are encased within a hard envelope, we find external gills, like those of many Mollusks; and these are attached to the most movable parts of the body,—one or more pairs of legs

Fig. 147.*



* Circulating and Respiratory Apparatus of *Terebella*:—*a*, labial ring; *b*, *b*, tentacula; *c*, first segment of the trunk; *d*, skin of the back; *e*, pharynx; *f*, intestine; *g*, longitudinal muscles of inferior surface of body; *h*, glandular organ (liver ?); *i*, organs of generation; *j*, feet; *k*, *k*, branchiæ; *l*, dorsal vessel; *m*, dorso-intestinal vessel; *n*, venous sinus surrounding œsophagus; *n'*, inferior intestinal vessel; *o*, *o*, ventral trunk; *p*, lateral vascular branches.

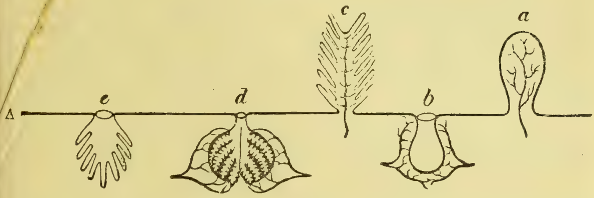
660. In this manner, the air that is introduced through the spiracles is carried into every part of the body of the Insect, and is brought into immediate relation with the tissues to be aërated; so that the carbonic acid which they set-free is communicated at once to the atmosphere, instead of being taken-up by the blood; and the oxygen they require is imbibed in the same manner. And thus we see how the respiration of this interesting class, which is unequalled for its energy when the body is in a state of activity, is provided-for without an active circulation of blood and without the presence of red corpuscles,—which elsewhere seem to be essential conditions of the interchange of oxygen and carbonic acid between the air and the tissues, wherever this takes place to any great extent.

661. In the Spider tribe, we return to a more concentrated form of the respiratory apparatus; but notwithstanding that it is limited within much narrower dimensions externally, it exposes a very large amount of surface on its interior. It consists of a series of sacs, much less numerous than in the lower Articulata, and not communicating with each other. Their lining membrane, however, is doubled into a series of folds, which lie in proximity with each other like the leaves of a book, and which thus present a very extensive surface within a very small space. Over this surface the blood is distributed in a minute capillary network; and thus it comes into immediate relation with the air which is received into the cavity through its aperture or spiracle. The alternate admission and expulsion of air seem to be provided-for, as in Insects, by movements of the body, which first empty the cavities or air-tubes by compression, and then allow them to be re-filled by their own elasticity, the pressure being relaxed. The respiratory cavities in the Spider-tribe have received the name of *pulmonary branchiæ;* from their analogy, on the one hand, with the lungs of higher animals, and, on the other, with the branchial sac or gill-cavity of the higher Crustacea, the gills in which are formed by prolongations of the lining membrane, corresponding with the leaf-like folds in the air-cavities of the Spider-tribe.

662. The accompanying diagram will give an idea of the relations of these different forms of the Respiratory apparatus, both amongst themselves, and with that of Vertebrata. Let the line A B represent the general surface of the animal, the continuations of that line on its upper side being its *external* prolongations, and those on the lower its *internal* prolongations or reflections. Now at *a* is seen the character of the simple foliaceous or leaf-like gill, such as is found in the lower aquatic animals; presenting merely a flat expanded surface in contact with the water, over which the blood may be distributed. At *b* is shown a correspondingly-simple inversion, such as that which forms the respiratory sac of the Iulus, having the blood-vessels distributed upon its walls. A higher form of the gill, such as is found in Fishes and in the higher

aquatic Invertebrata, is seen at *c*; the surface being greatly extended by sub-division into minute filaments. A more complex form of the pulmonary apparatus, such as is found in the higher Vertebrata, is shown at *d*; the blood being distributed, not merely

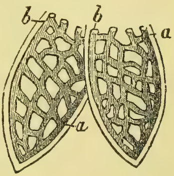
Fig. 150.*



to its outer walls, but to the minute partitions which subdivide its cavity into cells. And at *e* is represented the respiratory organ of the Spider-tribe, which bears an obvious resemblance to the lung of the Vertebrated animal shown at *d*; whilst it is evidently as nearly allied to the gill shown at *c*, provided this be imagined to be sunk within a cavity formed by a depression of the external surface, instead of projecting beyond this.—Thus we see how very close is the real resemblance between all the forms of the Respiratory apparatus, however unlike each other they may at first sight appear to be.

663. The gills of Fishes correspond with those of the higher Mollusca in all essential particulars; but they are more largely developed in proportion to the size of the body, being expanded into broader leaflets traversed by a capillary network (Fig. 151); and they are placed in a situation that enables them to receive a more regular and constantly-changed supply both of blood and of water. The gills are suspended to bony or cartilaginous arches, of which three, four, or more, are fixed on either side of the neck; and their fringes hang loosely within a cavity, which communicates on the one

Fig. 151.†



* Diagram illustrating different forms of the Respiratory apparatus: — *a*, simple leaf-like gill; *b*, simple respiratory sac; *c*, divided gill; *d*, divided sac; *e*, pulmonary branchia.

† Capillary network of a pair of leaflets of the Gills of the Eel: — *a*, *a*, branches of the branchial artery conveying venous blood; *b*, *b*, branches of the branchial vein, returning aërated blood. The disappearance of the dark shading in the network, as it traverses the gill. is designed to indicate the change in the character of the blood, as it passes from one side to the other.

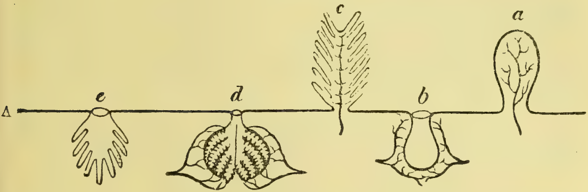
660. In this manner, the air that is introduced through the spiracles is carried into every part of the body of the Insect, and is brought into immediate relation with the tissues to be aërated; so that the carbonic acid which they set-free is communicated at once to the atmosphere, instead of being taken-up by the blood; and the oxygen they require is imbibed in the same manner. And thus we see how the respiration of this interesting class, which is unequalled for its energy when the body is in a state of activity, is provided-for without an active circulation of blood and without the presence of red corpuscles,—which elsewhere seem to be essential conditions of the interchange of oxygen and carbonic acid between the air and the tissues, wherever this takes place to any great extent.

661. In the Spider tribe, we return to a more concentrated form of the respiratory apparatus; but notwithstanding that it is limited within much narrower dimensions externally, it exposes a very large amount of surface on its interior. It consists of a series of sacs, much less numerous than in the lower Articulata, and not communicating with each other. Their lining membrane, however, is doubled into a series of folds, which lie in proximity with each other like the leaves of a book, and which thus present a very extensive surface within a very small space. Over this surface the blood is distributed in a minute capillary network; and thus it comes into immediate relation with the air which is received into the cavity through its aperture or spiracle. The alternate admission and expulsion of air seem to be provided-for, as in Insects, by movements of the body, which first empty the cavities or air-tubes by compression, and then allow them to be re-filled by their own elasticity, the pressure being relaxed. The respiratory cavities in the Spider-tribe have received the name of *pulmonary branchiæ;* from their analogy, on the one hand, with the lungs of higher animals, and, on the other, with the branchial sac or gill-cavity of the higher Crustacea, the gills in which are formed by prolongations of the lining membrane, corresponding with the leaf-like folds in the air-cavities of the Spider-tribe.

662. The accompanying diagram will give an idea of the relations of these different forms of the Respiratory apparatus, both amongst themselves, and with that of Vertebrata. Let the line A B represent the general surface of the animal, the continuations of that line on its upper side being its *external* prolongations, and those on the lower its *internal* prolongations or reflections. Now at *a* is seen the character of the simple foliaceous or leaf-like gill, such as is found in the lower aquatic animals; presenting merely a flat expanded surface in contact with the water, over which the blood may be distributed. At *b* is shown a correspondingly-simple inversion, such as that which forms the respiratory sac of the Iulus, having the blood-vessels distributed upon its walls. A higher form of the gill, such as is found in Fishes and in the higher

aquatic Invertebrata, is seen at *c;* the surface being greatly extended by sub-division into minute filaments. A more complex form of the pulmonary apparatus, such as is found in the higher Vertebrata, is shown at *d*; the blood being distributed, not merely

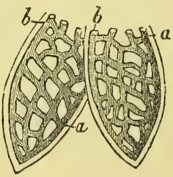
Fig. 150.*



to its outer walls, but to the minute partitions which subdivide its cavity into cells. And at *e* is represented the respiratory organ of the Spider-tribe, which bears an obvious resemblance to the lung of the Vertebrated animal shown at *d;* whilst it is evidently as nearly allied to the gill shown at *c*, provided this be imagined to be sunk within a cavity formed by a depression of the external surface, instead of projecting beyond this.—Thus we see how very close is the real resemblance between all the forms of the Respiratory apparatus, however unlike each other they may at first sight appear to be.

663. The gills of Fishes correspond with those of the higher Mollusca in all essential particulars; but they are more largely developed in proportion to the size of the body, being expanded into broader leaflets traversed by a capillary network (Fig. 151); and they are placed in a situation that enables them to receive a more regular and constantly-changed supply both of blood and of water. The gills are suspended to bony or cartilaginous arches, of which three, four, or more, are fixed on either side of the neck; and their fringes hang loosely within a cavity, which communicates on the one

Fig. 151.†



* Diagram illustrating different forms of the Respiratory apparatus: — *a*, simple leaf-like gill; *b*, simple respiratory sac; *c*, divided gill; *d*, divided sac; *e*, pulmonary branchia.

† Capillary network of a pair of leaflets of the Gills of the Eel: — *a, a*, branches of the branchial artery conveying venous blood; *b, b*, branches of the branchial vein, returning aërated blood. The disappearance of the dark shading in the network, as it traverses the gill. is designed to indicate the change in the character of the blood, as it passes from one side to the other.

hand with the mouth, and on the other with the exterior of the body. The mechanism of respiration is very complex in these animals; and is evidently adapted to produce the most effectual aëration possible. The mouth is first distended with water; and its muscles are then thrown into contraction, in such a manner as to expel the water through the aperture on either side of the pharynx, into the gill-cavity. At the same time, the bony arches are lifted and separated from each other by the action of muscles especially adapted to this purpose; so that the gill-fringes may hang freely, and may present no obstacle to the flow of the water between them. When they have been thus bathed with the aërating liquid, and their blood has undergone the necessary change, the water is expelled through the outward aperture on each side of the back of the neck; which is furnished with a large flap or valvular cover, termed the operculum.—In some of the Cartilaginous Fishes each branchial arch is inclosed in a separate cavity, which communicates on the inner side with the pharynx by an orifice peculiar to itself, and by another orifice with the external surface. Thus there is a series of external openings, instead of a single one, on each side of the neck; and these sometimes amount to six or seven, as in the Lamprey, reminding us of the spiracles of Articulated animals; whilst there is a corresponding series of internal openings into the pharynx on either side, or into a tube that communicates with it.

664. It is well known that most Fishes speedily die when removed from the water; and it can be easily shown that the deficient aëration of the blood is the immediate cause of their death. But as it might have been expected that the atmosphere would exert a much more energetic influence upon the blood contained in the gill, than that which is exercised by the air contained in the water, the question naturally arises how this deficient aëration comes to pass. It is chiefly due to the two following causes;—the drying-up of the membrane of the gills themselves when exposed to the air, so that the aëration of the blood is impeded;—and the flapping-together of the filaments of the gills, which no longer hang loosely and apart, but adhere in such a manner as to prevent the exposure of the greater portion of their surface to the air. Those fishes can live longest out of water, in which the external gill-openings are very small, so that the gill-cavity may be kept full of fluid; and there are certain species which are provided, like the Land-crab, with a particular apparatus for keeping the gills moist, and which perform long migrations over land in search of food, even (it is said) ascending trees. These are exceptions to the general rule.

665. The respiration of Fishes is much more energetic than that of any of the lower aquatic animals; and this is partly due to the great extension of the surface of the gills, partly to the provision just explained for maintaining a constant flow of fresh

water over their surface, and partly to the position of the heart at the base of the main trunk that conveys the blood to the gills (§ 558), by which the regular propulsion of that fluid through these organs is secured. Their blood, too, is furnished with red corpuscles, which give important aid in conveying oxygen from the gills to the remote tissues of the body, and in returning the carbonic acid to be excreted. The proportion of these varies considerably in the different species of the class, being very small in those that approach most nearly to the Invertebrata, while there is an entire absence of them in one remarkable fish, the *Amphioxus* or Lancelot; on the other hand they are present in large numbers in the blood of certain Fishes, which have great muscular activity and can maintain a high independent temperature.

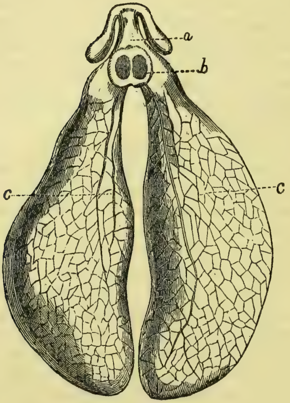
666. It would seem, however, that not even this high amount of respiration is always sufficient for Fishes which live in small collections of water, where their temperature is liable to be greatly augmented by the heat of summer; under which condition there is an increased proneness to disintegration in their tissues, and a corresponding necessity for the extrication of carbonic acid and for the absorption of oxygen. Many fresh-water fishes, under such circumstances, may be seen to come to the surface and to *swallow* air; and it would seem as if the interior of the intestinal canal then served the purpose of a respiratory surface, the air being expelled from the anus deprived of a large part of its oxygen and highly charged with carbonic acid.

667. In addition to their apparatus for aquatic respiration, many Fishes are provided, in their *air-bladder*, with the rudiment of the air-breathing apparatus of higher animals; although it is only in certain species which approach Reptiles in their general organization, that this really affords any aid in the aëration of the blood. The air-bladder in its simplest condition is entirely closed; and it is then obviously incapable of taking any share in the respiratory function, although it seems to be an organ of some importance to the animal, in regulating its specific gravity and thus altering its position in the water. In other cases, it communicates with the intestinal tube by a short wide canal, termed the *ductus pneumaticus;* and this may serve to admit air, which is taken into the alimentary tube by the process of swallowing just mentioned. In the Reptilian Fishes just adverted-to, the air-bladder forms a *double* sac, which is evidently the representative of the double lung of the air-breathing Vertebrata; and it communicates with the back of the mouth by a regular trachea or wind-pipe, which has a muscular valve at its commencement, serving to open or to close its orifice. Some of these fishes are able to live for a considerable time out of water, their respiration being maintained by these rudimentary lungs; and they can also make a hissing sound, by the expulsion of the air contained

in the air-sacs through the narrow glottis or entrance to the trachea.

668. The condition of the Respiratory apparatus, and the mode in which the function is performed, in the class of Reptiles, are peculiarly interesting; as it is in this class that we first meet with the complete adaptation of the Vertebrated structure to the aëration of the blood by the direct influence of the atmosphere. Their general habits of life require but a very feeble amount of aëration, especially at moderate temperatures; their muscular and nervous systems being usually exercised in a very low degree, their movements being sluggish, and their perceptions obtuse. In fact, they may be considered, on the whole, as the most vegetative of all Vertebrated animals. In accordance with this character, the lungs are so constructed as not to expose any very large amount of blood to the air at any one time; and, as we have already seen (§ 563), only a portion of the stream of the circulation is diverted to the lungs; the main current being sent to the system with only that amount of aëration which it has derived from the admixture of the portion of blood that has been aërated in the lungs, with the venous current that has last been returned from the system.

Fig. 152.*



669. The lungs of Reptiles are, for the most part, capacious sacs (Fig. 152), occupying a considerable part of the cavity of the trunk; but they are very slightly subdivided, so that the amount of surface they can expose is really small. Where any subdivision exists, it is usually at the upper extremity of the lung, near the point of entrance of the bronchial tube; and where there is no actual subdivision of the cavity, we usually find that the surface is extended in this situation, by the formation of a number of little depressions or sacculi in the interspaces of a sort of network of cartilage prolonged from

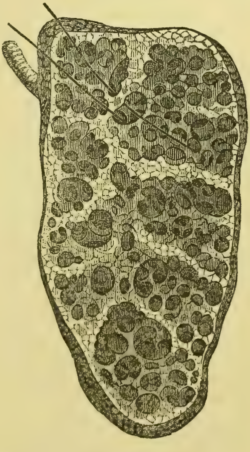
* Lungs of a Frog:—*a*, hyoidean apparatus; *b*, cartilaginous ring at the root of the lungs; *c*, pulmonary sacs, with reticulations marked out by cartilaginous framework.

the cartilage of the trachea. Upon the walls of these sacculi the blood-vessels are minutely distributed (Fig. 153), but in such a

Fig. 153.*

manner as to be exposed to the air on one side only. The greatest amount of subdivision is seen in the lungs of the Turtle tribe; but even in these, the partitions scarcely form a complete division at any part of the lungs; and the ultimate air-cells are of very large size (Fig. 154). The air-sacs of Reptiles are not filled, like those of Mammalia, by an act of inspiration, but by a process of swallowing, which is comparatively tedious; and from the small proportion which the aërating surface bears to the amount of air thus received into the cavity, one inflation of the air-sacs lasts for a considerable time. When the replacement of oxygen by carbonic acid has proceeded to an extent that renders the air no longer fit to remain in the lungs, these cavities are emptied by pressure exercised upon them by the muscles of the

Fig. 154.*



* Interior o upper part of Lung of Frog
† Section of the Lung of the Turtle.

trunk; and the slow exit of the air through the narrow glottis is accompanied by a prolonged hissing sound, which is the only sort of voice that is possessed by the greater part of the Reptile class. The lungs are again filled by the swallowing-process; and all goes on as before.

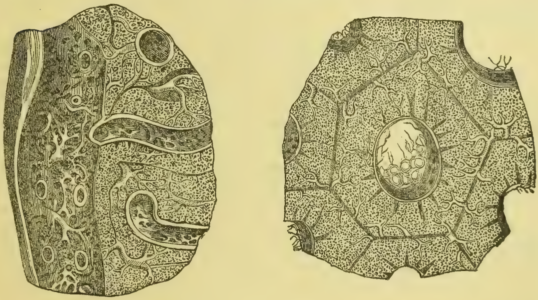
670. Now in the Frog tribe, which forms the lowest order of Reptiles (and which is sometimes ranked as a distinct class, under the title of Amphibia), the respiration during the early or *tadpole* state is aquatic; being carried-on by means of gills, and conducted exactly upon the plan of that of Fishes. The lungs are not developed until a period long subsequent to the animal's emersion from the egg; and as soon as they are ready to come into play, an alteration begins to take-place in the circulating system, by which the current of blood is diverted towards them, and away from the gills (§ 562). This change takes-place to its full extent in the Frog, Toad, Newt, and their allies; which henceforth have a respiration and a circulation exactly analogous to that of Reptiles in general; but it is checked in the Proteus, Siren, and other species which form the *perennibranchiate* group, —so called from the persistent character of their gills, which still remain in action, the lungs never being sufficiently developed to maintain the respiration by themselves.

671. This order *Batrachia* is further distinguished from other Reptiles, even when the metamorphosis is complete, by the softness and nakedness of the skin, which is destitute of the scales and horny plates that cover it in the Lizards, Serpents, and Tortoises. The Skin of the Frog tribe is a very important organ of respiration, being richly supplied with blood-vessels, and exposing their contents to the influence of the air under circumstances nearly as favourable as those afforded by the imperfectly-developed lungs of these animals. Thus a Frog from which the Lungs have been removed, will live for a considerable time at a moderate temperature, if its skin be freely exposed to a moist air; for in consequence of the peculiar mode in which the circulation is carried-on in these animals (§ 561), the interruption to the flow of blood through the lungs does not (as in the higher classes) produce a stagnation of the general current through the body; and the blood receives, in its course through the Skin, a sufficient amount of aëration for the support of life. Indeed at a low temperature, the influence of water on the skin is sufficient (by means of the air included in the liquid) to remove the small amount of carbonic acid then ready for excretion, and to supply the requisite amount of oxygen; and Frogs may thus live beneath the water for any length of time, without coming to the surface to breathe. But with the rise of the temperature of their bodies, their blood requires a higher degree of aëration; and they then come to the surface to take in air by the mouth, so as to aërate the blood sent

through the lungs. It appears that during the heat of summer, the pulmonary respiration and the influence of the water on the skin are not sufficient; as it is found that Frogs die if they be confined to the water under such circumstances,—their natural habit being to quit the water at this time, so that the air may exert its full influence on their skin as well as on their lungs. They do not, however, quit the neighbourhood of water, and soon die if exposed to a dry atmosphere; for if the skin becomes dry, its aërating function can be no longer performed. The same result happens, if the passage of gases through the skin be impeded by smearing it over with any unctuous substance.—We shall presently find reason to believe that this Cutaneous respiration is a very important part of the function even in Man and the Mammalia.

672. The class of Birds presents a most striking contrast to that of Reptiles, in regard to the energy of the respiratory function, and the extent of the apparatus destined to its performance; yet it is remarkable that the general plan of their pulmonary apparatus approaches more nearly to that of Reptiles than to that of Mammals. For the entire mass of each lung may be considered as subdivided into an immense number of lobules or 'lunglets,' each of which resembles the lung of a Frog in miniature; having a central cavity (Fig. 155, B) that communicates with a bronchial

A *Fig.* 155.* B



tube of its own (A), and has its walls strengthened by a network of cartilage derived from the cartilage of that tube. But the passages which go forth in the interspaces of that network enter a solid

* Interior structure of Lung of Fowl, as displayed by a section (A) passing in the direction of a bronchial tube, and by another section (B) cutting it across.

plexus of very minutely distributed blood-vessels, which do not seem to be covered by any limiting membrane, but which admits air freely into its meshes; and thus its cavities are in immediate relation with air on all sides, a provision that is obviously very favourable to the complete and rapid aëration of the blood they contain. In addition to the lungs, we find large air-sacs communicating with them, disposed in different parts of the body,—such as the abdominal cavity, the interspaces among the muscles, the spaces between the muscles and the skin, &c. These very greatly increase the respiratory surface; their lining membrane being extremely vascular, and adapted to expose the blood to the influence of the air. In most Birds, the bones themselves are hollow; and the lining membrane of their cavities serves as an additional aërating surface, the air being introduced into the interior of the bones by canals that communicate directly with the lungs. So free is this communication, that the respiration has been known to be maintained through the fractured humerus of an Albatross, when an attempt was made to destroy the bird by compressing its trachea. Thus the respiratory surface is extended into the remoter parts of the system, very much as in Insects; and the hollowness of the bones, together with the presence of numerous air-sacs in different parts of the body, contribute to diminish its specific gravity. The large quantity of air thus included in different portions of the frame, also serves, like that contained in the air-sacs of Insects, as a reservoir for the supply of the principal aërating organs during active flight, when the respiratory movements are less free.

673. The mechanism of Respiration in Birds is very different from that which produces the respiratory movements in Mammalia. The cavities of the chest and thorax are not yet separated by a Diaphragm, except in a very small number of species that approach most nearly to the next class. But, on the other hand, the whole cavity of the trunk is more completely enclosed in a bony casing; the ribs being connected with the sternum by osseous prolongations from the latter, instead of by cartilages; and the sternum itself being so largely developed, as to cover almost the entire front of the body. Now the natural condition of this bony framework is such, that when no pressure is made upon it, the cavity it encloses is in a state of distension; and the state of emptiness can only be produced by a forcible compression of the framework, through an exertion of muscular power. The lungs, instead of being freely suspended in the cavity of the chest, as in Mammalia, are attached to the ribs; and their own tissue is endowed with a degree of elasticity which causes them to dilate when they are permitted to do so. In the state of distension, therefore, which is natural to the cavity of the trunk, the lungs are expanded and fill themselves with air which they draw-in

through the trachea; and this condition they retain, until, by the action of the external muscles upon the bony framework, the cavity of the trunk is diminished, and the air is expelled from the lungs and air-sacs, which are again filled as soon as the pressure is taken-off.—As the air-sacs chiefly communicate with the part of the lungs that is most distant from the trachea, the air has to traverse the whole extent of those last organs, both when it is being drawn into the air-sacs, and when it is being expelled from them; so that it is made to serve for the aëration of the blood in the most effectual manner.

674. Thus the Respiratory apparatus of Birds, although not constructed upon so high a plan as that of Mammals, is enabled, by the extension of the aërating surface through the body, to bring the air and the blood into most intimate relation; and the energy of the function is further provided-for by the mode in which the pulmonary circulation is carried-on (a distinct heart, as it were, being provided for it, § 564), as well as by the arrangement of the blood-vessels, which transmit to the respiratory organs the whole of the blood that has been returned in a carbonated state by the great veins of the system. The very large proportion of red corpuscles contained in the blood gives additional effect to these provisions. The very high amount of respiration which is natural to Birds, and which cannot be suspended even for a short time without fatal consequences, has a direct relation (as already explained) with their extraordinary muscular activity, as well as with the high bodily temperature they are fitted to maintain, which cannot be lowered in any great degree without the suspension of their other functions. Birds are peculiarly susceptible of impurities in the atmosphere; and it has been shown by experiment, that if a Bird, a Mammal, and a Reptile, be placed together in a limited quantity of air, which gradually becomes vitiated by their respiration, the Bird will die first, the Mammal next, and the Reptile last. Or if the Bird be placed alone in a limited quantity of air, and be left until the atmosphere is so vitiated as to be no longer capable of supporting its life, a Mammal will still live for a time in that atmosphere; which, when no longer fit to sustain the life of the Mammal, may be further breathed by the Reptile without injury for a considerable period.

3. *Mechanism of Respiration in Mammals and in Man.*

675. It is in the class Mammalia that we find the Respiratory apparatus presenting its highest degree of concentration, and the arrangements for its action the most complete. The Lungs are divided into cavities of extreme minuteness, so that the extent of surface which they expose is enormously increased. These cavities,

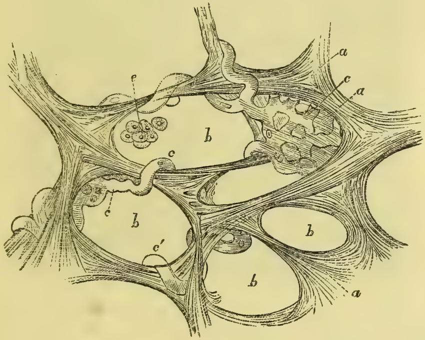
or air-cells, are all connected with the trachea, by means of the bronchial tubes and their minute subdivisions; but on account of the minuteness of these passages, a considerable force would be required to inflate the air-cells with air, if their distension were to be accomplished by the propulsion of air through the trachea, which we have seen to be the normal mode of inspiration in Reptiles. Moreover, if the air were introduced in this manner, the air-cells would be the *last* portions of the pulmonary structure that would be distended by it, as well as the first to be emptied when the air is forced-out again by external pressure. The mechanism of Respiration in Mammalia, however, is so arranged, that the air is most effectually *drawn into* the lungs, instead of being *forced into* them; and the distension of the air-cells is far more complete than it could be rendered in the latter method, besides being accomplished in a much shorter time.

676. The general principle of the operation is this:—The lungs are suspended in a cavity that is completely closed; being bounded above and around by the bony framework of the thorax, the interspaces of which are filled-up by muscles and membranes; and being entirely cut-off by the diaphragm from the abdomen below. Under ordinary circumstances the lungs completely fill the cavity; their external surface, covered by the pleura, being everywhere in contact with the pleural lining of the thorax. But the capacity of the thoracic cavity is susceptible of being greatly altered by the movements of the ribs, and by the actions of the diaphragm and abdominal muscles; as will presently be explained in more detail. When it is diminished, the lungs are compressed, and a portion of the air contained in them is expelled through the trachea. On the other hand, when it is increased, the elasticity of the air within the lungs causes them immediately to dilate, so as to fill the vacuum that would otherwise exist in the thoracic cavity; and a rush of air takes-place down the air-tubes towards the air-cells, to equalize the density of the air they include (which has been rarefied by the dilatation of the containing cavities) with that of the surrounding atmosphere.

677. Each of the ultimate ramifications into which the bronchial tubes are minutely subdivided, communicates with a cluster of air-cells grouped about its dilated termination; thus forming a lobule or lunglet, which represents the frog's lung in miniature, save in a very important particular to be presently noticed. The air-cells, which are in immediate proximity with the tube, open into it by well-defined circular apertures; and the others communicate with it by opening into these and into each other. The diameter of the air-cells of the Human lung varies from about the 1-200th to the 1-70th of an inch. Their shape is irregular; and their walls are, for the most part, flattened against each other. Each air-cell (Fig. 156, *b*, *b*, *b*) is lined by an extension of the

mucous membrane from the bronchial tubes; and this is furnished with a covering of pavement-epithelium (*e*). Between the adjacent air-cells is a network of fibrous tissue (*a*, *a*, *a*), that forms the connecting medium by which they are held-together; this tissue

Fig. 156.*



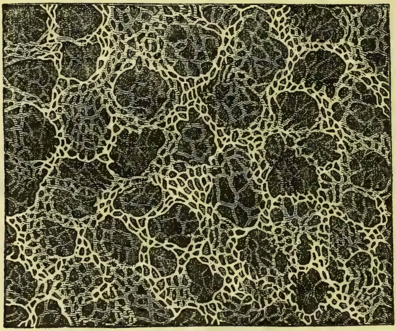
is chiefly of the elastic kind. The pulmonary arteries subdivide into branches, whose ultimate ramifications form an extremely minute capillary plexus (Fig. 157); and this is so disposed between the walls of the adjacent air-cells, that each portion of this plexus comes into relation with the air (through the lining membrane of the contiguous air-cells) on *both* sides,—an arrangement which is obviously the most favourable that can be, as regards the aëration of the contained blood. It has been calculated by M. Rochoux, that the number of air-cells grouped around each terminal bronchus is little less than 18,000; and that the total number in the lungs amounts to *six hundred millions.* If this estimate be even a remote approximation to the truth, it is evident that the amount of surface exposed by the walls of these minute cavities, must be very many times greater than that of of the whole exterior of the body.

678. The larger Bronchial tubes are more or less cartilaginous; but the smaller branches do not possess any such deposit in their

* Thin section of the Lung of an Infant, showing its minute structure:—*a*, *a*, *a*, bands of elastic fibrous tissue, lying between the air-cells *b*, *b*, *b*; *c*, *c*, *c*, capillaries forming a plexus underneath the basement-membrane of the air-cells; *e*, epithelium-cells,

walls, though still retaining their circular form. We find in the latter a fibrous structure, which seems to possess the properties of non-striated muscle; and by this the diameter of these tubes

Fig. 157.*



appears to be governed. The contractility of the walls of the smaller bronchi may be excited by chemical, electrical, or mechanical stimuli applied to themselves; though it is not so readily caused to manifest itself by stimulating the nerves. By the continued influence of galvanism, bronchial tubes of a line in diameter have been made to contract until their cavity was nearly obliterated; and it has been found by Volkmann that a similar effect may be produced by galvanising the Par Vagum. Supposing the muscular fibres of the bronchial tubes to contract during expiration, the effect of such contraction would be to diminish both the length and the diameter of the tubes, and thus to force-out their contained air. Whether such contraction, alternating with relaxation, takes place automatically, as a part of the ordinary rhythmical movements of respiration, has not yet been clearly made-out; but in its tonic form it manifests itself strongly in certain diseased conditions, especially in spasmodic Asthma, which appears essentially to consist in a contracted state of the smaller bronchial passages, occasioning an interruption to the passage of air through them. It is interesting to observe, that the contractility of the muscular walls of these tubes has been experimentally found to be greatly diminished by the application of vegetable narcotics, especially stramonium and belladonna, — substances which are well-known to have a powerful remedial influence in spasmodic Asthma.

* Arrangement of the Capillaries of the air-celis of the Human Lung.

679. The tissue of the parenchyma of the Lungs (§ 677) is possessed of a degree of elasticity which prevents these organs from being by any means passive in the respiratory function. This is seen in the collapse which takes-place when the thoracic cavity is laid-open; but as the lungs do not by any means completely empty themselves of air, even when quite free to do so, it is obvious that a partially distended state of these organs is that which is induced by the properties of their own structure, a fuller dilatation or a complete expulsion of the contained air requiring some external force for its production. Now even when the expiratory effort has been most powerful, the lungs are not more emptied of air than they are when left entirely free; whilst every degree of inspiratory effort will have to overcome their elasticity, the resistance caused by which will be proportional to the distension, amounting, for the fullest possible inspiration, to as much as 150 lbs. for the male and $123\frac{1}{2}$ lbs. for the female.

680. The dilatation of the cavity of the chest, which constitutes Inspiration, is accomplished by two sets of movements;—the elevation of the ribs;—and the depression of the diaphragm. From the peculiar mode in which the ribs are articulated with the spinal column at one extremity, and from the angle which they make with the cartilages that connect them to the sternum at the other, the act of elevation tends to bring the ribs and the cartilages more into a straight line, and to carry the former to a greater distance from the median plane of the body, whilst the sternum is also thrown forwards. Consequently, the elevation of the ribs increases the capacity of the thorax, upwards, forwards, and laterally. The movement is chiefly accomplished by the Scaleni muscles, which draw-up the first rib; and by the Intercostals, which draw the other ribs into nearer proximity with each other, so that the total amount of movement in each rib increases as we pass from above downwards,—every one being drawn-up by its connection with the one above it, and being drawn nearer to it by the action of its own intercostals. The elevation of the ribs is further assisted by the Serratus magnus, and by other muscles connected with the spine and the scapula; and when the respiratory movement is very forcibly performed, the scapula is itself drawn upwards by the muscles that descend to it from the neck, thus producing an increased elevation of the ribs, and an unusual enlargement of the upper part of the thoracic cavity.—When the Expiratory action is to be performed, the descent of the ribs is occasioned by the muscles of the spine and abdomen, which proceed upwards from the lower part of the trunk; and this action is aided by the elasticity of the costal cartilages.—The aid which the elasticity of the parietes of the chest gives to the expiratory movement, and the consequent resistance which it makes to the inspiratory movement, is a very

important element in the estimate of the force put-forth by the muscles. It is stated by Dr. Hutchinson as the results of his experiments, that the introduction of 70 cubic inches of air into a chest of moderate capacity requires a force of 104 lbs.; that when 190 cub. in. are forced-in, the elastic pressure to be overcome is 326 lbs.; and that when 200 cub. in. are made to enter, the pressure rises to 452 lbs.;—and this independently of the elastic pressure of the lungs themselves.

681. In the ordinary act of inspiration, however, the Diaphragm performs the most important part. The contraction of this muscle changes its upper surface, from the high arch that it forms when relaxed and pushed-upwards by the viscera below, to a much more level state; though it never approaches very closely to a plane, being somewhat convex even when the fullest inspiration has been taken. When thus drawn down, it presses upon the abdominal viscera, and causes them to project forwards, which they are allowed to do by the relaxation of the abdominal muscles. In tranquil breathing, this action is alone nearly sufficient to produce the requisite enlargement of the thoracic cavity: the position of the ribs being very little altered.—In the expiratory movement, the diaphragm is altogether passive; for, being in a state of relaxation, it is forced upwards by the abdominal viscera, which are pressed inwards by the contraction of the abdominal muscles. These last, therefore, are the main instruments of the expiratory movement; diminishing the cavity of the chest by elevating its floor, at the same time that they draw its bony framework into a narrower compass.

682. In this manner, by the regularly-alternating dilatation and contraction of the Thoracic cavity, the air within the Lungs is alternately increased and diminished in amount; and thus a regular exchange is secured. This exchange, however, can only affect at any one time a certain proportion of the air in the lungs; thus it is probable that the quantity remaining in these organs after a *forced* expiration is from 75 to 100 cubic inches, and that the air which remains after an *ordinary* expiration is about 150 cubic inches, whilst the amount usually changed by the respiratory movements is not above 20 cubic inches. Indeed, if it were not for the tendency of gases to mutual diffusion, the air in the remote air-cells would never be renewed.—If any aperture exist by which air could obtain direct access to the pleural cavity, the lungs will not be dilated by its enlargement; for the vacuum will be supplied much more readily by the direct ingress of the air (provided the aperture be large enough) than by the distension of the lung. Thus a large penetrating wound of the thoracic cavity may completely throw out of use the lung of that side; and the same result will follow when an aperture forms by ulceration in the substance of the lung itself, establishing a free communication

between the pleural cavity and one of the bronchial tubes; so that, of the air which rushes-in by the trachea to compensate for the enlargement of the thoracic cavity, a great part goes at once into that cavity without contributing to the distension of the lungs, and therefore without serving for the aëration of the blood.

683. The number of the Respiratory Movements (that is, of the acts of inspiration and expiration taken together) may be probably estimated at from 14 to 18 per minute, in a state of ordinary health and of repose of body and mind. Of these the greater part are moderate in amount, involving little movement except in the diaphragm; but a greater exertion, attended with a decided elevation of the ribs, is usually made at every fifth recurrence. The frequency of the respiratory movements, however, is liable to be greatly increased by various causes, such as violent muscular exertion, mental emotion, or quickened circulation; whilst it may be diminished by torpidity of the nervous centres on whose agency the movement depends,—as we see in apoplexy, narcotic poisoning, &c. An acceleration seems very constantly to take-place in diseases which unfit a part of the lung for the performance of its function; and the rate bears a proportion to the amount thus thrown out of use. Thus, the usual proportion between the respiratory movements and the pulse being as 1 to 4½ or 5, it may become in Pneumonia as 1 to 3, or even in severe cases as 1 to 2; the increase in the number of respiratory movements being much greater in proportion, than the augmentation of the rate of the pulse. But it must be remembered by the practitioner, that a simply hysterical state may produce, in young females, an extraordinary acceleration of the respiration; the number of movements being sometimes no less than 100 per minute. There will be a great increase, also, in the number of inspirations, when the regular movements are prevented from being fully performed by any cause that affects their mechanism, even whilst the lungs themselves are quite sound. Thus in inflammation of the pleura or pericardium, or in rheumatic affections of the intercostal muscles, the full action of the ribs is prevented by the pain which the movements produce; and the same is the case in regard to the diaphragm, when the peritoneum or the abdominal viscera are affected with inflammation. Under such circumstances, there is an involuntary tendency to make-up for the deficiency in the *amount* of the respiratory movements, by an increase in their *number*.

684. The combined actions of the Respiratory Muscles which have been now explained, belong to the group termed *reflex;* being the result of the operation of a certain part of the Nervous centres, which does not involve the Will, or even Sensation, and which may continue when all the other parts of the nervous

centres have been removed. In the Invertebrated Animals, we commonly find a distinct ganglionic centre set apart for the performance of the respiratory movements; and the division of the nervous centres in Vertebrated animals, which is the seat of the same function, may be clearly marked-out, although it is not so isolated from the rest. It is, in fact, that segment of the Medulla Oblongata and upper part of the Spinal Cord, which is connected with the 5th, 7th, and 8th pairs of cephalic nerves, and with the phrenic. The entire brain may be removed from above (by successive slicing), and the movements of the diaphragm will still continue,—those of the intercostal and other muscles being of course suspended by the destruction of that portion of the Cord from which their nerves arise. But if the spinal cord be divided between the point at which it receives the 5th and 8th pairs of nerves, and that at which it gives origin to the phrenic, the movements of the diaphragm immediately cease; and this is the reason why death is so instantaneous in cases of luxation or fracture of the higher cervical vertebræ, causing pressure upon the spinal cord just below its exit from the cranium; whilst if the injury take-place below the origin of the phrenic nerve, life may be prolonged for a limited time.

685. The Respiratory movements, like other reflex actions (§ 393), depend upon a *stimulus* of some kind originating at the extremities of the nerves, propagated towards the centre by the afferent trunks, and there giving-rise to a motor impulse, which is transmitted along the efferent or motor nerves to the muscles, and which occasions their contraction. Now the importance of the respiratory function to the maintenance of life, which has already been sufficiently pointed-out, necessitates an ample provision for its due performance; and thus we find that the stimulus for the excitement of the movements may be transmitted through several channels. Its chief source, no doubt, is in the lungs; and arises from the presence of venous blood in the capillaries, and of carbonic acid in the air-cells. Under ordinary circumstances,—that is, when the blood is being duly aërated, and the air being properly renewed,—the impression thus made upon the nerves of the lungs is so faint, that we cannot perceive it even when we specially direct our attention to it. But if we suspend the movements for a moment or two, we immediately experience a sensible uneasiness. The Par Vagum is obviously the channel through which this impression is conveyed to the nervous centres; and it is found that if the trunk of this nerve be divided on both sides, the respiratory movements are greatly diminished in frequency. Hence it is undoubtedly one of the principal *excitors* of the respiratory movements.

686. But the sensory nerves of the general surface, and more particularly the sensory portion of the Fifth pair which supplies

the face, are most important auxiliaries as *excitor* nerves; the inspiratory movement being peculiarly and forcibly excited by impressions made upon them, especially by the contact of cold air or water with the face. The power of the impression made by the air upon the general surface, and particularly upon the face, in exciting the inspiratory movement, is well seen in the case of the first inspiration of the new-born infant, which appears to be excited solely in this manner. An inspiratory effort is often made as soon as the face has emerged from the Vagina of the mother; whilst on the other hand, if the face be prevented from coming into contact with cool air, the inspiratory effort may be wanting. When it does not duly take place, it may often be excited by a slap with the flat of the hand upon the nates or abdomen; a fact which shows the special influence of impressions upon the general surface, in rousing the motor impulse in the Medulla Oblongata, and in causing its transmission to the muscles. The deep inspirations which follow a dash of cold water upon the face, or the descent of the cold douche or of the divided streams of the shower-bath upon the body, or the shock of immersion in the cold plunge-bath, all testify to the powerful influence of such impressions in the adult; and the efficacy of other kinds of irritation of the skin, such as beating with holly-twigs, in maintaining the respiratory movements in cases of narcotic poisoning, shows that the required impressions are not restricted to the contact of cold air or water. It seems probable, from various facts, that the presence of venous blood in the arterial capillaries of the system, and the consequent stagnation in the current through them (§ 597), may exert an influence through the Sympathetic nerves, which may be transmitted, by the copious inosculations of that system with the Par Vagum, to the Medulla Oblongata, and which may there serve as a valuable auxiliary in exciting the respiratory movements.

687. The impression thus transmitted to the Medulla Oblongata, excites a motor impulse which issues from it, along the phrenic, intercostal, and other nerves, so as to call forth the requisite muscular movements. When the stimulus is unusually strong, various nerves and muscles are put in action which do not co-operate in the ordinary movements of inspiration; and it may sometimes be observed that movements are thus excited in parts which will not act in obedience to the Will, being to all appearance completely paralysed. This fact shows how completely the class of actions in question is independent of the influence of the mind; but we must not lose sight of the control which the mind, especially in the higher classes of animals, possesses over them. Various actions of the respiratory muscles, particularly those of weeping and laughing, are the most direct means of expressing the passions and emotions of the mind; and are

involuntarily excited by these. And, again, the respiratory actions are placed to a certain degree under the control of the Will; in order that they may be subservient to the production of vocal sounds, and to the actions of speech, singing, &c. The will cannot long *suspend* the respiratory movements; for the stimulus to their involuntary performance soon becomes too powerful to be any longer resisted. And it is well that it should be so; for if the performance of the most important functions were left to our own choice, a few moments of forgetfulness would be productive of fatal results. But it is to the power which the will possesses, of directing and controlling the respiratory movements, that we owe the faculty of producing articulate sounds, as well as vocal tones of every description, and thus of holding the most direct and intimate converse with each other.

688. It is essential, for the performance of the Respiratory Movements, that the portion of the Nervous Centres on which they depend should be in a state of activity. This is the case, under ordinary circumstances, throughout life. The state of perfect quiescence to which the Brain is liable, never affects the Medulla Oblongata; and the respiratory movements are consequently kept up with as much regularity and energy (in proportion to the requirements of the system) during our sleeping as during our waking hours. But if any cause induce torpidity of the medulla oblongata, the respiratory movements are then retarded, or even suspended altogether; and all the consequences of the cessation of the aëration of the blood speedily develope themselves (§ 706). This is seen in Apoplexy, when the pressure or other cause of suspended activity, which at first affected the brain alone, gradually propagates its influence downwards. The same is the case in narcotic poisoning, in which also the brain is the first to be affected, and may suffer alone; but if the noxious influence be propagated to the medulla oblongata, it manifests itself in the retardation of the respiratory movements, and, when sufficiently powerful, in their complete suspension. Under such circumstances, it is requisite to resort to all possible means of keeping-up the respiratory movements by impressions on the excitor nerves, such as the application of cold (alternating with heat) to large parts of the surface; and when these fail, respiration may be maintained by the transmission of the magneto-electric current along the course of the phrenic nerve. For if, by such means, the circulation can be prevented from failing for a sufficient length of time, the ordinary processes of nutrition go-on, the poisonous matter is gradually decomposed or is eliminated by the secreting organs, and the nervous centres resume their usual functions.

4. *Chemical Phenomena of Respiration.*

689. Having now fully considered the means by which the Atmosphere and the Blood are brought into relation in the lungs, we have to examine into the results of their mutual action. It will be remembered that the Atmosphere contains about 21 per cent. of Oxygen to 79 of Nitrogen, by *measure;* or 23 parts of Oxygen to 77 of Nitrogen, by *weight.* The changes which it undergoes in Respiration may be considered under four heads:—1. The disappearance of Oxygen which is absorbed. 2. The presence of Carbonic Acid which has been exhaled. 3. The absorption of Nitrogen. 4. The exhalation of Nitrogen. Of these, the first two are by far the most important.—It was formerly supposed that the Oxygen which disappears, is the precise equivalent of the Carbonic Acid which is set-free (the latter gas containing its own bulk of the former); and that the union of the absorbed oxygen with the carbon to be eliminated, takes-place in the lungs. It is now known, however, that the carbonic acid is given-out ready formed, its production having taken-place at the expense of oxygen previously contained in the blood; and that a much larger proportion of oxygen is usually absorbed than is contained in the carbonic acid exhaled, the difference sometimes exceeding the third part of the carbonic acid formed, whilst it is sometimes so small that it may be disregarded. This diversity seems to depend, partly upon the constitution of the species experimented-on, and partly upon the degree of development of the individual, but in great part upon the nature of the food; the experiments of MM. Regnault and Reiset having established that the quantity of oxygen absorbed into the system is much greater on an animal diet that on a farinaceous. It is certain that, of this absorbed oxygen, a part must enter into combination with the sulphur and phosphorus of the original components of the body, converting these into sulphuric and phosphoric acids; and the remainder must enter into other chemical combinations, a large share uniting with the hydrogen of the fatty matter, to form part of the water which is exhaled from the lungs.

690. This interchange would seem to depend upon the tendency which all gases have to mutual admixture, when they are separated by a porous septum (§ 650). According to the law discovered by Prof. Graham, the relative volumes of the gases which will thus replace each other are inversely as the square-roots of their specific gravities; thus, the specific gravity of oxygen being to that of hydrogen as 16 to 1, the 'replacing volume' of oxygen is to that of hydrogen as 1 to 4. The same holds-good when one of the gases is absorbed by a liquid; provided the replacing gas be also capable of being absorbed to the same extent. On

this principle, the replacing volume of oxygen is to that of carbonic acid as 1174 to 1000; but as the actual amounts interchanged do not constantly follow this ratio, it is obvious that they are liable to be modified by other conditions, these being chiefly (it seems probable) the relative quantities of the two gases already present in the blood, and the relative facility with which they are absorbed into it or extricated from it.

691. It is difficult to form an exact estimate of the actual quantity of Carbon thrown-off from the lungs in the form of Carbonic Acid during any lengthened period; since the amount disengaged during experiments carried-on for a limited time, cannot, for many reasons, be taken as affording a fair average. Thus the quantity will vary with the external temperature, with the state of previous rest or activity, with the length of time that has elapsed since a meal, and particularly with the general development of the body. The amount of carbonic acid exhaled is greatly increased by external cold, as is shown in the results of such experiments as the following:—Small Birds and Mammals having been enclosed in a limited quantity of air, for the space of an hour, at ordinary temperatures, the quantity of carbonic acid they produced was noted. The experiment was then repeated at a temperature nearly approaching that of the body; and was performed a third time at a temperature of about 32°. The following are the comparative amounts.

	Temp. 59°—68°. Grammes.	Temp. 86°—106°. Grammes.	Temp. about 32°. Grammes.
A Canary	0·250	0·129	0.325
A Turtle-dove	0·684	0·366	0·974
Two Mice	0·498	0·268	0·531
A Guinea-pig	2·080	1·453	3·006

Thus it would appear, that the quantity of carbonic acid exhaled between 86° and 106° is not much more than *half* of that which is exhaled between 59° and 68°; and is only about *two-fifths* of that which is given-off at 32°.—These results accord well with observations on the relative amounts of Carbon exhaled by the Human subject in winter and summer; these were estimated by M. Barral in his own case at 10·8 oz. and 7·8 respectively.

692. The quantity of Carbonic Acid exhaled during exercise and for a certain time after it, and also after a full meal, is considerably increased; whilst on the other hand it is greatly diminished during sleep. Thus a person who was excreting 145 grains of carbon per hour whilst fasting and at rest, excreted 165 after dinner, and 190 after breakfast and a walk; whilst he only excreted 100 during sleep. The variation with the general development of the body, and also with the sex and age, is con-

siderable. Thus the exhalation is almost always greater in males than in females of the same age, at every period of life except childhood.—In *males*, the quantity increases regularly from eight to thirty years of age, remaining nearly stationary until forty: thus it averages 77·5 grains of carbon per hour at eight years; 135 grains at fifteen; 176·7 grains at twenty; and 189 grains from thirty to forty. Between forty and fifty there is a well-marked diminution, the average being then 156 grains; and the diminution continues up to extreme old age, when the amount exhaled scarcely exceeds that which is extricated at ten years of age; thus, between sixty and eighty, it was 142·5 grains; and in a man of a hundred and two, it was only 91·5 grains. These average results, however, are widely departed-from in individual cases; an extraordinary development of the muscular system being always accompanied by a high rate of extrication of carbon, and *vice versâ*. Thus a man of remarkable muscular vigour, whose age was twenty-six years, exhaled 217 grains of carbon in an hour; a robust man of sixty exhaled 209·4 grains; and an old man of ninety-two, who in his younger days had possessed uncommon muscular powers, and who preserved a remarkable degree of energy, still gave-forth at the rate of 151 grains per hour. On the other hand, a man of slight muscular development, at the age of forty-five, only exhaled 132 grains; and another at the age of seventy-six, only 92·4 grains.

693. In *females*, nearly the same proportional increase goes-on up to the time of puberty; when the quantity abruptly ceases to increase, and remains stationary so long as menstruation continues regular. The average quantity of carbonic acid exhaled by girls nearly approaching puberty, is about 100 grains per hour; and it remains at this standard until nearly the close of menstrual life. At the period of the cessation of the catamenia, it undergoes a perceptible increase; the average between forty and fifty years of age being about 130 grains per hour, and the quantity exhaled in a woman of great muscular development, and of forty-four years of age, rising to 152·4 grains in an hour. After the age of fifty, or thereabouts, the quantity decreases, as in men. It is remarkable that during pregnancy there is the same increase in the exhalation of carbon, as there is after the final cessation of the catamenia; and the same takes-place, if the menstrual discharge be temporarily suspended through any other cause.

694. It is obviously difficult, then, to obtain exact estimates, from any experiments conducted for a short time only, of the total amount of Carbon thrown-off during a lengthened period; since the condition of the same individual varies so much at different times, and the variation amongst different individuals is so great. Moreover, of the total amount of carbon excreted in a gaseous form, a certain part is undoubtedly set-free from the skin; but

the proportion of this does not seem to be considerable. As a means of measuring the whole quantity of carbonic acid set-free, without causing the respiratory movements to be performed in any unnatural manner, Prof. Scharling constructed an air-tight chamber, of dimensions sufficient to allow an individual to remain in it for some time without inconvenience, and so arranged that he could eat and drink, read or sleep, within it.* This was connected with an apparatus by which the air was continually renewed; and the air drawn-off was carefully analysed, in order to determine the quantity of carbonic acid contained in it. The average per hour in different states having been ascertained, it was calculated, that, allowing seven hours for sleep in adults, and nine hours for children, the *total* amount of carbon consumed in the twenty-four hours would be as follows:—

No.		Weighing	Grains.		Oz. Troy.
1.	A male, aged thirty-five,	131 lbs.	3387	or	7·0
2.	A male, aged sixteen,	115½ lbs.	3453	or	7·2
3.	A soldier, aged twenty-eight,	164 lbs.	3699	or	7·7
4.	A girl, aged nineteen,	111 lbs.	2540	or	5·3
5.	A boy, aged nearly ten,	44 lbs.	2054	or	4·3
6.	A girl, aged ten,	46 lbs.	1930	or	4·0

695. This estimate is unquestionably too low, as it does not take sufficient account of the great increase which is produced by exercise. The recent researches of Dr. Edward Smith, whilst agreeing well with those of Prof. Scharling as to the amount of carbon given-off while the body is at rest, lead him to estimate that it increases to about 8·7 oz. when an average amount of exercise is taken, and to 11·7 oz. when severe bodily labour is undergone. In a subsequent series of experiments, Prof. Scharling ascertained the proportion of carbonic acid given-off from the general surface of the human body, to be from about 1-30th to 1-50th of the whole amount; so that, adopting 1-40th as the average, out of eight ounces of carbon exhaled, only one-fifth of an ounce is set-free in the form of carbonic acid from the Skin.

* This method of experimenting has been recently carried out with greater exactitude by MM. Pettenkofer, and Voit; whose results are in general accordance with those stated above. Dr. Edward Smith's method, on the other hand, consists in the use of a small portable Gas-meter, connected with a mask that is so fitted to the face as to allow Respiration to be performed as naturally as possible. This gas-meter registers the total quantity of Air passing through the Lungs; and by exposing within it a large surface of Caustic Potass, it can be made to absorb the whole of the Carbonic acid from the expired air. Although less exact in its indications as regards a subject at rest, it is obvious that Dr. E. Smith's method is capable of being applied in a much greater variety of modes, when the object is to determine the effects produced upon Respiration by such exercises as that of the tread-wheel, climbing mountains, &c., to which Dr. E. Smith has subjected himself with the most laudable self-sacrifice.

696. The *total amount* of Air which passes through the Lungs in the course of 24 hours, has been estimated by Valentin and Dr. Edward Smith at about 400 cubic feet; but the laborious researches of the latter enquirer have shown that it undergoes a very marked increase with every degree of muscular effort that is put forth. Thus the ordinary exercise of the unoccupied gentleman would raise the amount to about 466 cubic feet; the more active life of a tradesman would augment it to above 600 cubic feet; the hard work of a labourer to above 900 feet; and the severe toil of Alpine climbing for twelve hours to 1,000 feet. The exertion of carrying weights (as by the soldier in marching order) was found to increase the amount of air passing through the lungs in a very regular ratio, that of 7 cubic inches for every 1 lb. weight carried.

697. If we assume 8 oz. of solid Carbon as the total amount excreted from the lungs of a male adult using moderate exertion, in the course of twenty-four hours, we find that the volume of carbonic acid thus generated must be about 29,500 cubic inches, or 17 cubic feet. Taking the whole quantity of air which passes through the lungs during that time under similar circumstances, at about 466 cubic feet, we find the proportion of Carbonic acid contained in the expired air to average about 3·6 per cent. It is certain, however, that this proportion may rise much higher; particularly when the respiratory movements are slowly and laboriously performed. In order that the blood should be properly aërated, it is requisite that the air should contain no previous impregnation of Carbonic acid; since the diffusion of even a moderate per-centage of that gas through the inspired air seriously impedes the exhalation of more. Thus it was found by Messrs. Allen and Pepys, that when 300 cubic inches of air were respired for three minutes, only $28\frac{1}{2}$ inches of carbonic acid (or somewhat more than 9 per cent.) were present in it; though the rate of its production in a parallel experiment, in which fresh air was taken in at each inspiration, was 32 cubic inches per minute, or 96 cubic inches in three minutes.

698. It appears from the experiments of Dr. Snow, which have been confirmed by those of later enquirers, that the presence of Carbonic acid in the atmosphere acts more deleteriously on the system, in proportion as the normal quantity of Oxygen has been reduced; and hence the *substitution* of carbonic acid for oxygen by the respiratory process, vitiates the air far more effectually than the introduction of a *surplus* of carbonic acid, the normal quantity of oxygen being still present. He concludes from his experiments upon the lower animals, that 5 or 6 per cent. of Carbonic acid cannot exist in an atmosphere respired by Man without danger to life; but that less than half this amount would soon be fatal, when it is formed at the expense of the Oxygen of the

air. A still smaller proportion is capable of producing very injurious results. Thus the discomforts occasioned by the presence of a crowded audience in a church, lecture-room, or theatre, which is not provided with sufficient ventilation, are due in a great part to the continued respiration of air in which carbonic acid is substituted for oxygen in the course of an hour or two, to the amount of from one-half to two per cent.,—as has been ascertained both by direct experiment, and by calculation. And there can be no reasonable doubt that the habitual respiration of such air, in the narrow and noisome dwellings of the poor, or in crowded factories and workshops, has a tendency to produce, both directly and indirectly, much loss of physical and mental vigour, and also to blunt the acuteness of the moral feelings. Its influence is specially noticed in increasing the predisposition to epidemic diseases, and in augmenting the fatality of their attacks.

699. The effects of a simple deficiency of Oxygen in the respired air, are experienced by those who breathe a rarefied atmosphere, such as that which exists on the summits of high mountains. All persons who have made such ascents, have experienced the insufficiency of rarefied air to sustain the degree of respiration required for active exertion. So long as the body remains at rest, no inconvenience is perceived; but as soon as the muscular system is put into action, the insufficiency of the supply of oxygen is manifested by the feeling of distress and languor, which becomes so severe, that the individnal, if unused to such ascents, is obliged to stop and take breath at every few steps. The necessity for doing so will be easily understood, when it is remembered that when the *pressure* of the atmosphere is reduced to *half* its usual amount, the *bulk* of a given weight of air will be *twice* as great as at the surface of the earth, or the *same* measure will weigh only *half* as much. Consequently, when the chest is completely filled with air, the real quantity of oxygen included in it, is only half of that which is drawn-in by a corresponding inspiration at the earth's surface.

700. With regard to the absorption and exhalation of Nitrogen, it seems probable that both these processes are constantly going on; but that their relative activity varies under different conditions. Thus it has been ascertained by MM. Regnault and Reiset, that although warm-blooded animals, when subjected to their ordinary regimen, usually increase the amount of nitrogen in the atmosphere, yet when food is withheld, or the animals are fed upon a diet to which they are unaccustomed, an absorption of nitrogen takes-place; this being particularly remarkable in the hybernating Mammalia, in which the gain in weight by the absorption of oxygen and nitrogen even exceeds the loss occasioned by the exhalation of carbon.

701. The Blood parts in the Lungs with a very large amount of

Water; for the inspired air is always saturated with fluid as soon as it reaches the air-cells; and as it is heated at the same time to about 98°, it thus receives a considerable addition even if previously charged with as much as it could contain at a lower temperature. The total quantity of fluid thus disengaged will vary, therefore, with the amount previously contained in the atmosphere, being greater as this was less, and *vice versâ;* but the quantity that usually passes-off seems to be from 16 to 20 ounces in the twenty-four hours. It cannot be doubted that a great part of this water is a simple exhalation of that which has been absorbed; but, on the other hand, it has been proved by a comparison of the hydrogen of the food with that given-off by other excretions, that a portion of it must be actually formed in the system, by the union of a portion of the oxygen absorbed in the lungs with the hydrogen of the combustible matters of the blood (§ 197). In the various forms of saccharine and farinaceous aliments, the proportions of hydrogen and oxygen are such as would of themselves form water when the carbon is withdrawn; but in oily and fatty matters, the proportion of oxygen is far too small thus to neutralize the hydrogen; and thus, by their oxidation in the blood, as by their combustion elsewhere, Water is actually generated by the union of atmospheric oxygen with their hydrogen, at the same time that Carbonic acid is produced by its union with their carbon.

702. It has been recently ascertained that the Watery vapour that issues from the lungs holds in solution minute quantities of Uric acid, Urates of Soda and Ammonia, and the Chlorides of Sodium and Ammonium. But a far more important product of the Pulmonary exhalation is an Organic compound, which seems to be an Albuminous substance in a state of change, and the amount of which may be estimated (according to the method of Dr. Angus Smith) by its effect in discolouring the permanganate of potass. If the vapour be condensed in a closed vessel, and be exposed to warmth, a very evident putrid odour is exhaled from it; and the accumulation of such miasmatic emanations by *overcrowding* probably conduces far more to the spread of Zymotic disease, than simple want of elimination of Carbonic acid would do; its effect being precisely that of the diffusion of a sewer atmosphere through the respired air.

5. *Effects of Insufficiency, or Suspension, of the Aërating Process.*

703. The change which the Blood undergoes, by being brought into relation with atmospheric air in the respiratory organs, is so important to life, that the entire suspension of it inevitably produces a fatal termination at no remote period; and if it be insufficiently performed, various disorders in the system are nearly

sure to manifest themselves. The state which is induced by the entire suspension of the aërating process, is termed *Asphyxia;* a word which literally means the absence of pulse, and which would be applicable therefore to the stoppage of the circulation from any cause, though it is usually employed to designate the particular condition resulting from suspended respiration. Asphyxia may be produced in aquatic animals, as well as in those which breathe air, by cutting them off from the influence of the atmosphere; for if a Fish be placed in water from which the air has been expelled by boiling, it is precisely in the condition of an air-breathing animal placed in a vacuum, since it has no power of obtaining oxygen by decomposing the water it inhabits, and is entirely dependent for the aëration of its blood upon the air that is absorbed by the liquid. Again, if a fish be placed in water impregnated with carbonic acid, its death is nearly as instantaneous as that of an air-breathing animal immersed in an atmosphere of that gas.

704. Asphyxia may result from a great variety of causes. Thus there may be a mechanical obstruction to the entrance of air through the trachea; as in hanging, strangulation, or drowning; or as in occlusion of the aperture of the glottis by œdema of its lips, or by the presence of a foreign body in the larynx. Or, again, the passage may be perfectly free, and yet no air may enter, in consequence of some obstacle to the performance of the respiratory movements. This obstacle may be mechanical; as when a quantity of earth has fallen round the body, in such a manner as to completely prevent the distension of the chest and abdomen. Or it may result (and this is a most frequent occurrence) from torpidity or complete inactivity of the ganglionic centre which is concerned in the respiratory actions, or from interruption to the transmission of its influence along the nervous trunks. Further, when there is no obstacle to the free ingress or egress of air, Asphyxia may be produced by the want of oxygen in the atmosphere that is respired, or by the presence of carbonic acid in too large an amount. And the presence of other gases which exert a directly poisonous influence on the blood,—such as sulphuretted hydrogen,—produces a state which may be included under the same general description.

705. Now when, from any of these causes, the free exchange of carbonic acid for oxygen in the blood passing through the lungs is checked, the first effect of the interruption appears to be the stagnation of that blood in the pulmonary capillaries. This stagnation is evidently due, not to any deficiency of power in the heart, for that organ is not yet affected; but to the insufficiency of the heart's power, acting alone, to drive the blood through the pulmonary capillaries, the force which should be generated by chemical changes in them (§ 597) being deficient. The stagnation

is not, however, complete at first; since the quantity of oxygen contained in the lungs is sufficient to produce an imperfect arterialization of the blood; and the blood thus partially changed is transmitted to the left side of the heart, and is thence propelled to the system. Owing to its half-venous condition, it cannot exert its usual stimulating influence on the tissues, especially the muscular and nervous; and their powers are consequently weakened. For the same reason, it does not receive its usual auxiliary force in the systemic capillaries (§ 597); since the changes which it ought to undergo in them can only be partially performed.

706. As the air included in the lungs loses more and more of its oxygen, and becomes more and more charged with carbonic acid, the aëration of the blood in the pulmonary capillaries becomes more and more imperfect; the quantity of blood which is allowed to return to the heart is gradually diminished, and its condition becomes more and more venous; and at last the pulmonary circulation is altogether suspended. From the relation which the respiratory circulation bears to the systemic, in all the higher classes of animals save Reptiles, it follows that the systemic circulation must in like manner be brought to a stand. The venous blood accumulates in the pulmonary artery, in consequence of the obstruction of its capillaries; it distends the right cavities of the heart; and the accumulation extends to the venous system of the body in general, especially affecting those organs which naturally receive a large quantity of venous blood, such as the liver and spleen. The arterial system, on the other hand, is emptied in a corresponding degree; nearly all its blood having passed through the systemic capillaries, and no fresh supplies being received from the heart. From this deficiency, and from the venous character of the blood which the systemic arteries *do* contain, it results that the nervous and muscular systems lose their power; insensibility comes-on, at first accompanied with irregular convulsive movements; but in a short time there is a total cessation of all movement, except that of the heart; and the pulsations of that organ become feebler and feebler, until they cease altogether. The immediate cause of the cessation of the heart's action appears to be different on the two sides. Both are equally affected by the want of arterial blood in the capillaries of their own substance; but the right side suffers from over-distension, which produces a sort of paralysis of its muscular tissue; whilst the left side retains its contractility, but is not excited to contraction for want of the stimulus of arterial blood in its cavities.

707. In those warm-blooded animals, which are not endowed with any special provision for enabling them to sustain life during the prolonged suspension of the respiratory process, insen-

sibility and loss of voluntary power almost invariably supervene within a minute and a half after the admission of air to the lungs has been entirely prevented; though the respiratory efforts and convulsive actions which are dependent upon the Medulla Oblongata and Spinal Cord, may continue for a minute or two longer. The circulation generally comes to a complete stand within ten minutes at farthest.—The chief exceptions are in the case of diving animals, which are provided with large arterial and venous reservoirs, that serve to maintain the circulation during a prolonged suspension of the respiratory process; for the arterial plexuses being ordinarily filled, they afford a supply of aërated blood to the systemic capillaries when other blood is wanting; and the reservoirs connected with the venous system, which were previously empty, receive this blood, and prevent it from exercising undue pressure upon the heart. To such an extent is this provision carried in some animals, that the Whale has been known to remain under water for an hour. Another exception exists in the case of hybernating Mammals (§121), which are reduced for a time to the condition of cold-blooded animals, and which can, like the latter, sustain a prolonged suspension of the aërating process. And there is reason to believe that in the state of Syncope or fainting,—in which the circulation is already reduced to a very low amount in consequence of a partial failure in the heart's power, all the functions of the body being nearly suspended, and the demand for aëration being consequently very small,—the respiration may be suspended for a long period, even in the Human subject, without fatal results. Thus more than one case has been credibly recorded, in which recovery has taken-place after complete submersion for more than three quarters of an hour; and it is probable that in these instances a state of Syncope came-on at the moment of immersion, through the influence of mental emotion or of concussion of the brain.

708. In the restoration of an animal from the state of Asphyxia, it is above all things of importance to renew the air in the lungs; for in this way the blood in the pulmonary capillaries will be aërated, the capillary circulation will be re-established, the right side of the heart will be relieved of its excessive load of venous blood, and the left side will receive the stimulus of a fresh supply of arterial blood; so that, if its movements have not ceased altogether, it may be speedily restored to due activity. At the same time the temperature of the body should be kept-up by artificial warmth, and the circulation in the skin should be excited by friction. Where no other means are at hand for introducing pure air into the lungs (of which means the application of galvanism along the course of the phrenic nerve, so as to produce contraction of the diaphragm, will probably be the most effectual), the object may be attained by alternately raising the arms above

the head (which, by elevating the ribs will augment the capacity of the thorax, § 680), and then bringing them down to the sides again, when the thorax will collapse. In this manner a large proportion of the carbonic acid may be expelled, and a considerable proportion of fresh air introduced, in the course of a few minutes. If air be blown into the lungs by bellows, great care must be taken to prevent the employment of too much force, which is likely to produce rupture of the air-cells.

709. Now when, from the more prolonged action of various causes that impede the due performance of the Respiratory function, the aëration of the blood in the lungs is insufficient for health, though not such as to produce a complete stagnation of its movement, a variety of results may follow; of which some or others will manifest themselves, according to the condition of the general system, and the peculiarities of the individual. Thus deficient respiration seems to favour the retention of fatty matter in the system; and this is not merely in the condition of Adipose tissue, which (unless it accumulate to excess) may be regarded as a healthy product; but also in the place of the normal components of other tissues, as the muscular and glandular, giving-rise to the condition which is termed 'fatty degeneration.'—Again, the due elaboration of the plasma of the blood is undoubtedly prevented by an habitually-deficient respiration; and various diseases which result from the imperfect performance of this elaboration, consequently manifest themselves. The *Scrofulous* diathesis is thus frequently connected with an unusually small capacity of the chest.—Further, an habitual deficiency of respiration may impede, though it does not check, the circulation in the lungs; and thus a tendency arises, in various pulmonary diseases, to an overloading of the pulmonary arteries, to a dilatation of the right cavities of the heart, and to a congestion of the venous system in general, as marked by lividity of the surface, by venous pulsation, &c. This state may result, not merely from obstruction in the lungs themselves, but from deficiency of the respiratory movements, consequent upon torpidity of the medulla oblongata (as in apoplexy and narcotic poisoning), or upon partial interruption of the nervous circle requisite for all reflex movements. Thus when the Par Vagum is divided, the number of respiratory movements is greatly diminished, and a partial stagnation of the blood in the lungs is the result. The same happens in certain forms of typhoid fever, in which the respiratory movements are preternaturally slow, in consequence of torpidity of the medulla oblongata. Now in this state, an effusion of the watery part of the blood into the air-cells of the lungs (as in other cases of obstructed circulation) is very liable to occur; and when the lungs are thus loaded with fluid, the respiratory process is still more impeded, and the disorder has thus a tendency to increase itself.

CHAPTER X.

OF SECRETION.

1. *Of the Secreting process in general; and of the Instruments by which it is effected.*

710. We have seen that in the process of Nutrition, the circulating current not only *deposits* the materials which are required for the renovation of the solid tissues; but also *takes back* the substances which are produced by the decay of these, and which are destined to be thrown-off from the body. We have also seen that it supplies the materials of certain fluids which are separated from it to effect various purposes in the economy; such as the Salivary and Gastric fluids, which have for their office to assist in the reduction of the food. Now the process by which the fluids of the latter kind are separated from the Blood, is precisely the same in character as that by which the products of decay are eliminated from it; and the structure of the organs concerned in the two is essentially the same. Hence both processes are commonly included under the general term *Secretion*, which simply denotes *separation*. Considered in its most general point of view, this designation may be applied to *every* act by which substances of any kind are *separated* from the blood. Thus the elaborating action of the cells contained in the Absorbent and Vascular Glands (CHAP. VI., Sects. 2, 4) may be termed one of Secretion, because they draw from the nutritive fluids a supply of Albuminous matter, upon which their converting action is exercised: but as the product of their operation is returned to the circulating current, and is employed for higher purposes in the economy, the process is usually termed Assimilation. With much more justice, however, the process of Respiration may be regarded as one of Secretion; for it consists, as we have seen, in the constant elimination of a substance from the blood, which cannot be retained in it without the most injurious consequences.

711. There is an important difference in the characters of the principal products of the Secreting process, which is connected with the purposes that are to be answered by their separation. Some of these products are strictly *excrementitious;* that is, they are *altogether different* from the ordinary constituents of the fabric, and from the materials which the Blood supplies for the nutrition of these. So different are they, that their presence in the circulating current has an injurious effect; and the great object of their separation is the maintenance of the purity of the

blood. These poisons, for such they may be considered, are generated in the system by the decay and decomposition to which its several parts are liable; and they are just as noxious to it as if they were absorbed from without. We have seen that the retention of Carbonic acid in the blood for even a few minutes is fatal, both by putting a stop to the circulation, and by acting unfavourably upon the Nervo-Muscular apparatus. The same fatal result attends the retention of Urea and of Biliary matter, which are among the other products of the decomposition of the tissues; but although as certain, it is not so speedy, because the general circulation is not checked by the loss of secreting power on the part of the Kidneys and the Liver, and because the accumulation of the noxious matter is slower.—On the other hand, the ingredients that are met-with in those secreted fluids which are destined to answer some purpose in the economy, almost invariably bear a close correspondence with the ordinary materials of the Blood. Thus in the Salivary, Gastric, Pancreatic, and Lachrymal fluids, the principal part of the solid matter consists of the saline and of the albuminous constituents of the blood, the latter in a more or less altered condition. In Milk, again, we trace the ordinary constituents of the blood, with very little change. Thus it appears that the separation of *these* fluids is not required so much to maintain the Blood in a state of purity, as to supply what is needed for some subsequent operation in the economy; and hence if the secreting process be interrupted in the case of any one of them, the suspension has usually no further effect than that of disturbing the process to which the fluid is usually subservient. If the secretion of Gastric fluid be checked, for example, under the influence of strong mental emotion, the Digestive operation is prevented from taking-place.

712. The essential character of the true *Secreting* operation seems to consist,—not in the nature of the action itself, for this is identical with those of Assimilation and Nutrition, being (as we have seen, § 243), a process of cell-growth,—but in the position in which the cells are developed, and the mode in which the products of their action are afterwards disposed-of. Thus the epithelial cells at the extremities of the Intestinal Villi (§ 494), the cells of which the Adipose tissue is made-up (§ 228), and the cells contained in the follicles of the Mammary gland (§ 243), all have an attraction for fatty matter, and draw it from the neighbouring fluids at the expense of which they are developed, to store it up in their own cavities. But the cells of the first kind, when they have come to maturity, set-free their contents, which are delivered to the Absorbent vessels, to be introduced into the circulating current:—those of the second kind seem more permanent in their character, and retain their contents, so as to form part of the ordinary tissues of the body, until they are required to give them

up for other purposes, when the matters which they have temporarily separated from the circulating current are restored to it again without change;—and the cells of the third class, when *they* liberate their contents, cast them forth into the ducts by which they are conveyed to the outlet of the gland.

713. It is, then, in the *position* of the Secreting cells,—which causes the product of their action to be delivered upon a *free surface*, communicating, more or less directly, with an external outlet,—that their distinctive character consists. All the proper *Secretions* are thus either poured-out upon the exterior of the body, or into cavities provided with orifices that lead to it. Thus we shall see that a considerable quantity of solid matter, and a very large quantity of fluid, of which it is desirable that the system should be freed, are carried-off from the Cutaneous surface. Another most important secretion, containing a large quantity of solid matter, and serving also to regulate the quantity of fluid in the body,—namely, the Urinary,—is set-free by a channel expressly adapted to convey it directly out of the body. The same may be said of the Mammary secretion, which is separated from the blood, not to preserve *its* purity, nor to answer any purpose in the economy of the individual, but to afford nutriment to another being. And of the matters secreted by the very numerous glandulæ situated in the walls of the Intestinal canal, a great part are obviously poured into it for no other purpose than that they may be carried out of the body by the readiest channel.

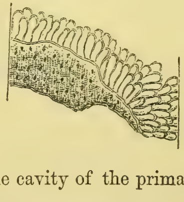
714. The cells covering the simple Membranes that form the free surfaces of the body, whether external or internal, are all entitled to be regarded as *secreting* cells; since they separate various products from the blood, which are not again to be returned to it. But the secreting action of some of these appears to have for its chief object the *protection* of the surface; thus the Epidermic cells secrete a horny matter, by which density and firmness are imparted to the cuticle (§ 245); whilst by the Epithelial cells of the Mucous membrane of the alimentary canal and of other parts, their protective Mucus seems to be elaborated (§ 238). But in general we find that special organs termed *Glands* are set-apart for the production of the chief secretions; and we have now to consider the essential structure of these organs, and the mode of their operation. A true Gland may be said to consist of a closely-packed collection of follicles (§ 243), all of which open into a common channel, by which the product of the glandular action is collected and delivered. The follicles contain the secreting cells in their cavities; whilst their exterior is in contact with a network of blood-vessels, from which the cells draw the materials of their growth and development (Fig. 44). In any one of the higher animals, we may trace-out a series of progressive stages of complexity in the various glands included

within their fabric; and in following any one of the glands that attain the highest degree of development (such as the Liver or Kidney), through the ascending scale of the Animal series, we should trace a very similar gradation from the simplest to the most complex form.

715. That there is nothing in the *form* or *disposition* of the the components of any Glandular structure, which can influence the character of the secretion it elaborates, is evident from the fact, that the very same product,—*e.g.* the Bile, or the Urine,—is found to issue from nearly every variety of secreting structure, as we trace it through the different groups of the Animal kingdom. The peculiar power by which one organ separates from the blood the elements of the Bile, and another the elements of the Urine, whilst a third merely seems to draw-off a certain amount of its albuminous and saline constituents, is obviously the attribute of the ultimate secreting cells, which are the real agents in the secreting process. *Why* one set of cells should secrete Bile, another Urea, and so on, we do not know; but we are equally ignorant of the reason for which one set of cells converts itself into Bone, another into Muscle, and so on. This variety in the endowments of the cells by whose aggregation and conversion the fabric of the higher animals is made-up, must be regarded (for the present as least) as one of the 'ultimate facts' of Physiological Science.

716. Passing-by the extended membranous surfaces, and the protective cells with which they are covered, we find that the simplest form of a secreting organ is composed of an *inversion* of that surface into a series of follicles, which discharge their contents upon it by separate orifices. Of this we have an example in the *gastric* follicles, even in the higher animals; the apparatus for the secretion of the Gastric fluid never attaining any higher condition than that of a series of distinct follicles, lodged in the walls of the stomach, and pouring their products into its cavity by separate apertures. In Fig. 158 is represented a portion of the Ventriculus succenturiatus of a Falcon, in which the simplest form of such follicles is seen. A somewhat more complex condition is seen in some of the Gastric follicles of the Human stomach (Fig. 120); the surface of each follicle being further extended by a sort of doubling upon itself, so as to form the commencement of secondary follicles, which open out of the cavity of the primary

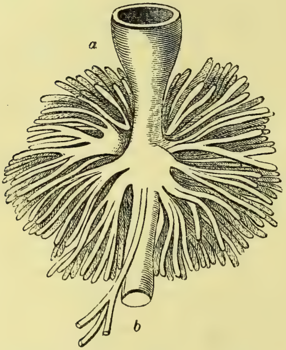
Fig. 158.*



* Glandular follicles in ventriculus succenturiatus of Falcon.

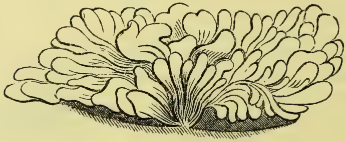
one.—Now a condition of this kind is common to *all* glands in an early stage of their evolution; and in this stage we meet with them, either by examining them in the lowest animals in which they present themselves, or by looking to an early period of their embryonic development in the highest. Thus, for example, the Liver consists, in Bryozoa and in the lowest Mollusca, of a series of isolated follicles, lodged in the walls of the stomach, and pouring their product into its cavity by separate orifices; these follicles being recognized as constituting a biliary apparatus by the colour of their secretion. So, again, the Pancreas first presents itself in the condition of a group of prolonged follicles, or *cæca*, clustered round the commencement of the intestinal tube; and this is its permanent condition in many Fishes (Fig. 159). And the Mammary Gland possesses an equally simple structure in the lowest of all Mammals (to which group it is restricted); namely, in the Ornithorhyncus (Fig. 160).

Fig. 159*.



717. The next grade of complexity is seen, where a cluster of the ultimate follicles open into one common duct, which discharges their product by a single outlet; a single gland often containing a number of such clusters, and

Fig. 160.†



having, therefore several excretory ducts. A good example of such a condition, in which the clusters remain isolated from one

* Rudimentary Pancreas from Cod :—*a*, pyloric extremity of stomach; *b*, intestine.

† Mammary Gland of Ornithorhyncus.

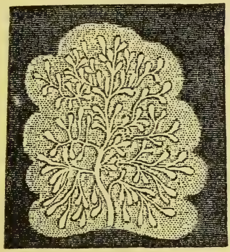
another, is seen in the Meibomian glands of the eyelid (Fig. 161); each of which consists of a double row of follicles, set upon a long straight duct, that receives the products of their secreting action, and pours them out upon the edge of the eyelid. And of the more complex form, in which a number of such clusters are bound together in one glandular mass, we have an illustration in the accessory glands of the genital apparatus in several animals,

Fig. 161.*

Fig. 162.†

which discharge their secretion into the urethra by numerous outlets (Fig. 162); or in the Mammary glands of Mammalia in general, the ultimate follicles of which are clustered upon ducts that coalesce to a considerable extent, though continuing to form several distinct trunks even to their termination. Such glands may be subdivided, therefore, into *glandulæ* or *lobules*, that remain entirely distinct from each other (Fig. 163).—In the highest form of Gland, however, all the ducts unite so as to form a single canal, which conveys away the products of the secreting action of the entire mass. This is the condition in which we find the Liver to exist in most of the higher animals; also the Pancreas, the Parotid Glands, and many others.

Fig. 163.‡

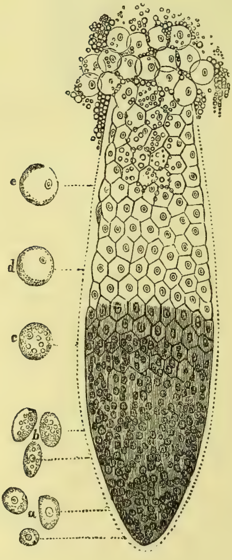


* Meibomian glands of upper lid of new-born infant.
† Portion of Cowper's gland from Hedgehog; the follicles distended with air.
‡ Lobule of Lachrymal Gland; from fœtal sheep.

In some of these cases we may still separate the gland into numerous distinct lobules, which are clustered upon the excretory duct and its branches like grapes upon a stalk; in others, however, the branches of the excretory duct do not confine themselves to *ramifying*, but *inosculate* so as to form a network, which passes through the whole substance of the gland, and connects together its different parts so as to render the division into lobules less distinct. This seems to be the case in regard to the Liver of the higher Vertebrata (§ 723).

718. Whatever degree of complexity, however, prevails in the general arrangement of the elements of the Glands in higher animals, these elements are themselves everywhere the same; consisting of *follicles* that enclose the real secreting cells (Fig. 164). Now from the history of the development of the Glands in general, it appears that the *follicles* may be considered as *parent-cells;* and that the *secreting* cells in their interior constitute a *second* generation, developed from the nuclei or germinal centres on the walls of the first. These closed cells become follicles, by opening at one extremity, either upon a neighbouring free surface, or into a canal which is prolonged from it. Thus the first rudiment of the Liver is formed by a thickening of the cellular mass in the walls of the alimentary canal, at the spot in which the hepatic duct is subsequently to discharge itself. This thickening increases, so as to form a projection upon the exterior of the canal; and soon afterwards the lining membrane dips-down into it, so that a kind of cæcum is formed, surrounded by a mass of cells, as shown in Fig. 165. The increase of the mass seems to be effected

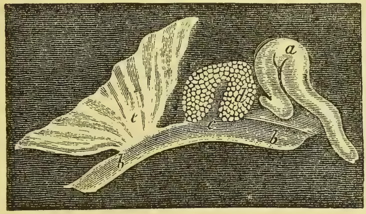
Fig. 164.*



* One of the Hepatic cæca of Astacus affinis, (Cray-fish), showing the porgress of development of the secreting cells from the blind extremity to the mouth of the follicle; examples of these, in their successive stages, are shown separately at *a*, *b*, *c*, *d*, *e*.

by a continual new budding-forth of cells from its peripheral portion, which takes-place to a considerable extent before the cæcum in the interior begins to ramify. Gradually, however, the cells of

Fig. 165.*



the exterior become metamorphosed into fibrous tissue for the investment of the organ; those of the interior break-down into ducts which form continuations of the principal canal; whilst those which occupy the intervening space, and which form the bulk of the gland, seem to be developed into follicles, and to give origin to the proper secreting cells. As this is going-on, the hepatic mass is gradually removed to a distance from the wall of the alimentary canal; and the cæcum is narrowed and lengthened so as to become a mere connecting pedicle, forming, in fact, the main trunk of the hepatic duct.—The development of the Pancreas, Salivary glands, &c., seems to follow the same plan.

719. Although it would seem to be a general rule that the gland-cells which draw into themselves the materials they are destined to separate from the blood, deliver these up again only by their own rupture or deliquescence, so that every act of Secretion is in fact an act of renewed cell-formation, yet it appears pretty certain that this is not always the case. For in those more liquid secretions which contain little else than water—as is the case with the Cutaneous transpiration and the Lachrymal fluid, as also in the Urine, of which the solid matter, though in considerably larger amount, is in a state of such perfect solution as to be capable of ready transudation,—neither do exuviated cells normally present themselves, nor do the epithelial cells lining the tubes or follicles present indications of being in a state of continual change. Still, even in these cases, it seems fair to conclude that the *selective* powers of the gland-cells are employed in drawing

* Origin of the Liver from the intestinal wall, in the embryo of the Fowl, on the fourth day of incubation:—*a*, heart; *b*, intestine; *c*, everted portion giving origin to liver; *d*, liver; *e*, portion of yolk-bag.

from the blood, on one side, the special products which are to be set free by transudation on the other.

2. *Of the Liver and the Bile.*

720. The Liver is more rarely absent than any other Gland; being discoverable, under some form or other, in all but the very lowest members of the Animal kingdom. Its simple condition in the lowest Mollusks has been already noticed (§ 716); and it is met-with under an almost equally simple form in the Star-fish. As we ascend the scale, however, we find it assuming a much greater importance, and presenting a great increase in size. This is particularly the case in the Molluscous classes; and also in the Crustacea, a class which, in mode of respiration and in general habits, bears a great resemblance to the Mollusca. In nearly all such animals, the Liver makes-up a large proportion of the mass of the body. It usually consists of a series of large follicles (Figs. 166 and 167) which branch-out into smaller ones (Fig. 164), and of

Fig. 166.*

Fig. 167.†

which several open into one excretory duct; but these ducts remain separate, and discharge their contents into the intestine by several distinct orifices.—In Insects and other air-breathing Articulata, however, the Liver is much less developed; and its type remains much simpler. We usually find it consisting of a small number of cæcal tubuli, which open separately into the intestinal canal just below the stomach. These tubuli are often so long as to pass several times from one extremity of the visceral cavity to the other, being doubled upon themselves; in other instances, we find that the principal tube or canal is beset with rows of short folli-

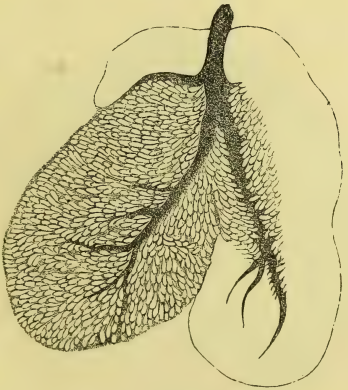
* Lobule of Liver of Squilla Mantis; exterior.

† Lobule of Liver of Squilla Mantis cut open.

cles, somewhat in the manner of Fig. 161; but they never cluster together so as to form a solid glandular mass. The low development of the liver in these animals bears an evident relation to the high development of their respiratory apparatus; whilst the respiration being comparatively feeble in the aquatic Mollusca and Crustacea, the development of the liver in those classes is enormous.

721. There is much difficulty in ascertaining the mode in which the elementary constituents of the Liver are arranged, in the fully developed condition of that organ in the higher Vertebrata. In that curious little fish, the *Amphioxus* or Lancelot, which retains the embryonic type in so many parts of its conformation, the Liver consists of a series of distinct cæcal follicles, clustered round a projection from the intestinal canal, and opening separately into it, very much as in the early embryo of the Fowl (Fig. 165). In the Tadpole, again, the distinct follicles seem very evident (Fig. 168); but here we see that the projection of the intestinal canal,

Fig. 168.*



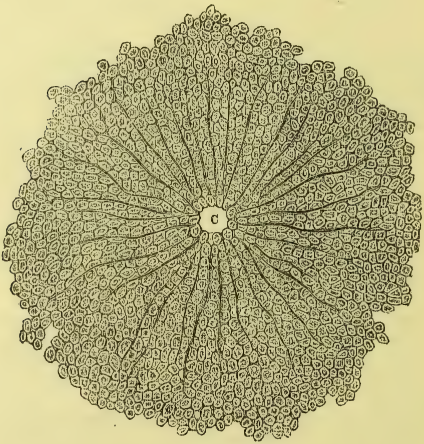
instead of being a simple wide cæcum, has become extended in length and contracted in diameter, at the same time dividing and sub-dividing, so as to form an arborescent excretory duct, whose ramifications extend through the entire glandular mass. In this manner, then, is formed the complex system of Hepatic Ducts,

* Liver of Tadpole; showing distinct and free cæcal terminations of the biliary ducts.

which we find in the liver of the higher Vertebrata, branching out from the main trunk. But the mode in which the ultimate ramifications of these are arranged, and their relations with the secreting cells which make-up the *parenchyma* of the gland, have not yet been ascertained beyond all doubt; though the researches of Prof. Beale have furnished important additional evidence in favour of the view that these cells are contained in the interior of *ducts*, the ramifications of which, instead of terminating in cæcal follicles, form by anastomosis a close reticulation through each lobule.

722. The entire Liver is made-up of a vast number of minute *lobules*, of irregular form, but about the average size of a millet-seed. Each of these lobules contains all the elementary parts of which the entire organ is composed; namely, branches of the hepatic artery and vein, branches of the portal vein, branches of the hepatic ducts, and secreting cells. The appearance which they present when cut-into, is shown in Fig. 169; where it is

Fig. 169.*



seen that the secreting cells are packed closely together into a

* Transverse section of a lobule of the Human Liver, showing the arrangement of the hepatic cells in lines radiating from the *Vena centralis*, the section of which is seen at c.

solid parenchyma, which is imperfectly divided into radiating segments by the peculiar disposition of the blood-vessels (Fig. 171). This parenchyma is minutely traversed by a capillary network, the interstices of which seem entirely filled by the secreting cells (Fig. 170); it appears probable, however, that these cells are

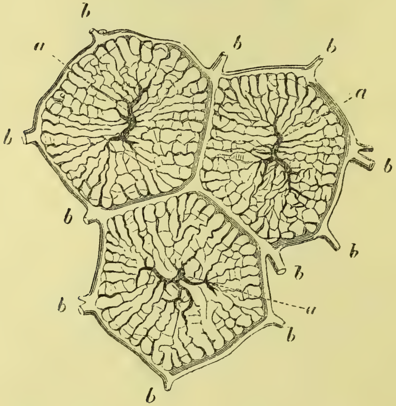
Fig. 170.*

really contained within a network of tubuli prolonged throughout the entire substance of each lobule from the plexus of ducts that surrounds it (Fig. 173), this network filling the whole space which intervenes between the capillaries of the lobular plexus. The lobules are bound together in part by connective tissue prolonged from what is known as 'Glisson's capsule;' but still more by the anastomosis of the blood-vessels and hepatic ducts which supply the adjacent lobules; indeed there is frequently no definite division of the glandular substance into lobules, other than that which is marked-out by the arrangement of these canals (Figs. 171 and 173). The branches of the *Hepatic Artery* are principally distributed upon the walls of the hepatic ducts, and upon the trunks and branches of the portal and hepatic veins, supplying them with their *vasa vasorum;* also upon Glisson's capsule and its prolongations into the substance of the liver. There is strong reason to believe that the blood which the liver receives from this source is not destined to supply the materials for the biliary secretion, until it has become venous by travelling through the capillary network, in which it is subservient to the nutrition of the tissues it permeates, as in other parts of the systemic capillary apparatus.—The supply of blood from which the materials of the biliary secretion are chiefly drawn, is afforded by the *Vena Portæ,* which collects it as a Vein from the chylopoietic viscera, and which then subdivides as an Artery to distribute it to the different

* Portion of parenchyma of the Human Liver injected, and highly magnified, showing the hepatic cells in the interspaces of the capillary network.

parts of the Liver. Its branches proceed to the capsules of the lobules, covering the whole *external* surface of the latter with their ramifications, and sending capillary twigs inwards, which converge towards the centre of each lobule (Fig. 171, *b*, *b*). As the principal branches of these veins ramify in the spaces between the lobules, they are termed *inter*-lobular veins.—On the other hand, the branches of the *Hepatic Vein* pass from the trunks to the centre of each lobule, from which they send out diverging capillary twigs (*a*, *a*) towards the circumference; and these last,

Fig. 171.*

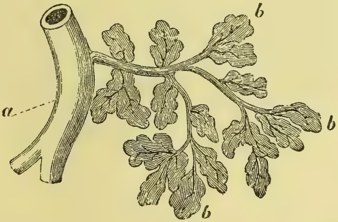


coming into connection with the converging capillaries of the portal vein, establish a free capillary communication between the interior and the exterior of each lobule. Thus the portal blood is first distributed to its exterior, then penetrates its interior, and then, after permeating its parenchymatous substance in numerous minutely divided streams, is collected and carried-off by the hepatic vein, of which a twig originates in the centre of each lobule. Owing to the peculiar position of the branches of the hepatic vein in the centre of each lobule, the lobules are appended to its main trunks almost in the manner of leaves upon a stem (Fig. 172).—The precise relation of the capillaries of the *Hepatic Artery* with

* Horizontal section of three superficial lobules of the Liver, showing two principal systems of blood-vessels; *a*, *a*, *intra*-lobular veins, proceeding from the Hepatic veins; *b*, *b*, *inter*-lobular plexus, formed by branches of the Portal veins.

those of the portal and venous systems, has not yet been well ascertained; but there seems reason to believe, with Mr. Kiernan, that the arterial capillaries discharge themselves into the ultimate ramifications of the portal vein; and that thus the blood of the former, having become venous by transmission through the nutritive capillaries of the liver, mingles with the other venous blood collected by the vena portæ, to supply the materials of the biliary secretion, which are eliminated during its passage into the hepatic vein.

Fig. 172.*

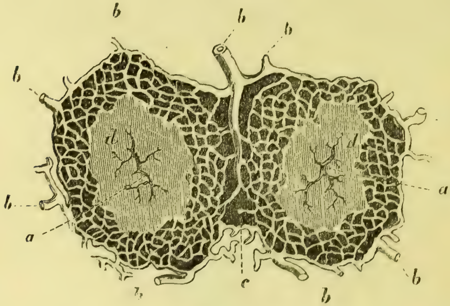


723. The *Hepatic Ducts* also seem to form a plexus which surrounds the lobules, connecting them together, and sending branches towards the interior of each (Fig. 173); and on the whole it seems most probable that a similar plexus extends throughout the substance of the lobule, filling-up the entire space not occupied by the blood-vessels (its membranous wall, however, being with difficulty traceable, owing to its extreme tenuity); and that the hepatic cells are contained within it, as within the follicles or tubes of ordinary glands. It is still maintained by some eminent Anatomists, however, that the cellular parenchyma of the Liver is comparable to that of the Peyerian bodies (§ 496), or of the Malpighian bodies of the Spleen (§ 513); and that the hepatic ducts do not enter far into the lobule, but only receive the products of its secreting action by the transmission of these through the successive cells from its interior to its exterior.—The Hepatic Cells (which are easily obtained in a separate condition by scraping a piece of fresh liver) are of a flattened spheroidal or polygonal form; and their diameter is usually from 1-800th to 1-1600th of an inch. Each cell presents a distinct nucleus, and it is usually around this that the yellowish hue of the cell is the

* Connection of the lobules of the Liver with the Hepatic vein :—*a*, trunk of the vein; *b*, *b*, lobules depending from its branches, like leaves on a tree; the centre of each being occupied by a venous twig,—the Intralobular Vein.

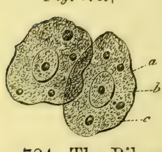
deepest; it seems doubtful, however, whether these cells have a distinct membranous wall. Their substance is composed of biliary matter, much of which is in the condition of fine granular particles too minute to be measured; but in the midst of these there

Fig. 173.*



are usually one or two large adipose globules, or five or six small ones (Fig. 174). The amount of this fatty matter, however, is liable to great variation (§ 725). The biliary matter which these cells contain, marks them out as the real agents in the secreting process; this process consisting, it is evident, in the growth of the hepatic cells, which, in the course of their development, eliminate from the blood the biliary matter for which they have a special affinity; and then discharge it by their deliquescence into the Hepatic Ducts, to be by them conveyed to the Intestine.

Fig. 174.†



724. The Bile which has been secreted by the hepatic cells, and which has found its way into the ramifications of the Hepatic Ducts, may be directly conveyed by the trunk of the latter into the intestine, or it may regurgitate along the Cystic duct into the Gall-bladder. It is probable that the secreting process is constantly going-on; although, as in other cases, it may vary in its degree of activity at different times. When the process of digestion is taking-place, and the small intestine is filled with chyme,

* Horizontal section of two superficial lobules, showing the interlobular plexus of Biliary Ducts:—*a*, *a*, intralobular veins; *b*, *b*, trunks of biliary ducts, proceeding from the plexus which traverses the lobules; *c*, interlobular tissue; *d*, parenchyma of the lobules.

† Glandular cells of Liver:—*a*, nucleus; *b*, nucleolus; *c*, adipose particles.

there is probably an uninterrupted flow of bile into its cavity; but when the intestine is empty, the bile seems not to be admitted into it, but rather to flow-back into the gall-bladder, in which it is stored-up, as in a reservoir, until the time when it may be needed. In this reservoir it undergoes a certain degree of concentration, by the absorption of its watery part; and it also becomes mixed with a large proportion of mucus, which is secreted by the walls of the gall-bladder.—Bile is a viscid, neutral or feebly-alkaline, somewhat oily-looking liquid, of a greenish-yellow colour, and very bitter taste, followed by a sweetish after-taste. It is readily miscible with water, and its solution froths like one of soap. The proportion of solid matter which the bile of the gall-bladder contains in the Human subject has been found to vary from 9 to nearly 18 per cent. Of this solid matter, about a twentieth consists of alkaline and earthy salts, corresponding with those of the blood; whilst the remainder is made-up of organic constituents. The composition of the organic solids of Bile as a whole may be represented, according to Liebig, by the formula C^{76}, H^{66}, N^{2}, O^{22}, with a certain amount of Sulphur; when this is compared with Blood, the formula for the organic solids of which is C^{48}, H^{39}, N^{6}, O^{15}, together with Sulphur, Phosphorus, and Iron, the preponderance of Carbon and Hydrogen is seen to be very marked, Nitrogen being almost entirely absent. The *Bilin*, or proper biliary matter, would seem from the researches of Strecker and Lehmann to be composed of two resinoid acids, the *Glycocholic* and the *Taurocholic*, which are combined with a soda-base. These acids are formed, according to Lehmann, by the 'conjugation' of a resinoid acid common to both of them, namely, *Cholic* acid,—whose composition is C^{48}, H^{39}, O^{9},—with *glycine* (gelatin-sugar) and *taurine* respectively. The latter substance is remarkable for the large proportion of sulphur—no less than 25 per cent.—which it contains; so that the proportion of taurocholic to glycocholic acid, which differs greatly in different animals, may be estimated by the amount of sulphur present in the mixture of the two. Besides a variable quantity of the ordinary fatty acids, Bile also contains a non-saponifiable fatty matter termed *Cholesterin;* this is a white crystallizable substance, somewhat resembling spermaceti, free from taste and odour, and composed almost entirely of Carbon and Hydrogen; its formula is C^{36}, H^{32}, O^{1}. The proportion of Cholesterin in healthy bile appears to be very small, and it is held in solution by the preceding ingredients; but in many disordered states, and especially in disease of the gall-bladder, this component is present in much larger amount; and it usually forms the principal, if not the sole ingredient in biliary concretions.—The Colouring matter of Bile is a substance distinct from the preceding; that of the Ox and other graminivorous animals appears to be identical, or nearly so, with the chlorophyll

of the leaves on which they feed; but that of Human bile seems to possess different properties, and to be derived from the proper constituents of the blood. This also occasionally accumulates so as to form concretions which consist of little else.

725. Regarding the destination and purposes of this secretion in the Animal economy, the following may be considered as a tolerably complete summary; though it is impossible to speak with precision on some points, since the organic constituents of the Bile are liable to be so easily altered by various reagents, that they are with difficulty recognized.—A portion of the Bile unquestionably passes off, in Man and most other animals, with the fæces; this portion, which includes the colouring matter, is probably that which is most purely *excrementitious*. But as the researches of Bidder and Schmidt have shown that only a small proportion of the Sulphur of the Bile is discharged per anum, and as its other constituents cannot be recognized in fæcal matters, it can scarcely be a question that, in the healthy state, the greater part of the solid matter of the Bile is destined for reabsorption, along with the newly-ingested alimentary substances (§ 482); to be finally, it is probable, carried-off by the respiratory process.—The secreting action of the Liver, however, by which a certain product is entirely separated from the blood, constitutes only a part of the action of that organ; since, as already shown (§ 493), the changes which it effects in the alimentary materials newly introduced into the current of the circulation, are at least equally important; and it has the further office of preparing the Hepatin which seems to constitute the ordinary *pabulum* of the Respiratory process (§§ 172, 537).—A large part of the bulk of the Liver, in many of the lower animals, is made-up of Oleaginous matter; which appears to accumulate in the hepatic cells, giving them almost the character of fat-cells, in proportion as the respiratory function is inactive. Thus the liver is very large and fatty in Mollusca and Crustacea; whilst in Insects, on the other hand, it is comparatively undeveloped. In Fishes, again, it is rich in oily matter; whilst in the liver of Birds scarcely any traces of fat are to be found. The amount of oily matter which has been shown to be ordinarily present in the hepatic cells of Man and other Mammalia (§ 723) is subject to great increase under circumstances which favour the increased deposition of Fat in the body generally, as we may notice in the livers of Sheep that have been fattened for the market. And in the 'fatty liver' of disease, the oil-globules constitute a large part of the components of the hepatic cells (§ 754).

726. The elements of the Bile may be altogether supplied by the disintegration of the tissues; and this must certainly be the case, when the amount of food taken is no more than enough to supply the *waste* of the system. We may regard it, then, as one

office of the Liver, to remove from the blood, and to convert into a form suitable for oxygenation by the respiratory process, such products of that disintegration as are rich in carbon and hydrogen. It may be pretty certainly affirmed, however, that biliary matter does not pre-exist *as such* in the blood, but that its elements must be originally present there under some more pernicious form. For it is found that the total suspension of the secreting action of the Liver, whereby the excrementious matter is left to accumulate in the blood, has a much more prejudicial effect upon the system, than the re-absorption of Bile after it has been secreted, in consequence of an obstruction to its discharge through the ductus choledochus; so that it may be inferred that the noxious products of the disintegration of the tissues are transformed into the comparatively-innocent components of Bile, in the very act of secretion.—But there can be little doubt that the Liver has also for its office, to draw-off from the blood any superfluity which may exist in the non-azotized compounds derived from the food, beyond the amount that is requisite for the supply of the respiratory process, or that can be deposited as fat. For we continually witness the results of habitual excess in the ingestion of such substances, in producing that state of the system commonly termed *bilious;* of which all the symptoms are referable to the accumulation of the elements of the bile in the blood, and the consequent deterioration in the purity of the circulating fluid. Where a tendency to such a state exists, proper means should be taken to stimulate the liver to increased activity; but the chief reliance should be placed on the avoidance of those articles of diet which contain a large proportion of hydrocarbon, and on abstinence from superfluous nutriment of any description.

3. *Of the Kidneys and the Urine.*

727. The Kidneys are perhaps the most purely *excreting* organs in the body; their function being to separate from the blood certain matters that would be injurious to it if retained, and these matters being destined to immediate and complete removal from the system. Some traces of Urinary organs may be detected in most of the higher Invertebrata; but it is in Fishes that they first present a considerable development; and in ascending through the Vertebrated series, we find them rapidly increasing in the complexity of their organization, and in their functional importance, although their size and extent are not so great. In Fishes, the Kidneys very commonly extend through the whole length of the abdomen; and they consist of tufts of uniform-sized tubules, which shoot-out transversely at intervals from the long ureter, and which are held together by a loose web of connective tissue that supports the network of vessels distributed upon their walls.

This condition of the Urinary organs is very analogous to that of the Corpus Wolffianum, or temporary kidney of the embryo of higher animals (Fig. 175, *f*). A similar condition is found in the true Kidney of higher animals at an early grade of development (as shown in Fig. 176); the tubuli uriniferi being short and straight. In their more advanced condition, however, they become long and convoluted; and the ramifications of the capillary vessels come into very close relation with them (Fig. 177). It is in the higher Reptiles that we first meet with the distinction between the *cortical* and the *medullary* substances; the former being the part in which the blood-vessels are most copiously distributed, and in which the tubuli have the most convoluted arrangement; and the latter consisting chiefly of straight tubuli, converging towards the points at which they discharge themselves

Fig. 175.*

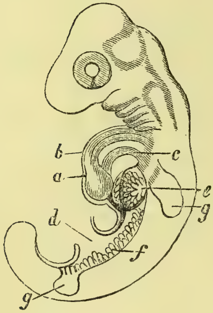


Fig. 176.†

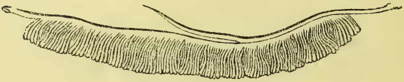
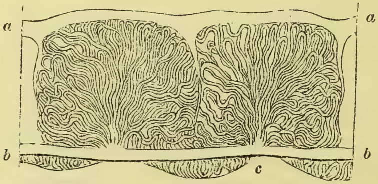


Fig. 177.‡



* Embryo of Green Lizard:—*a*, heart; *b*, duplex aorta; *c*, vena cava; *d*, intestine; *e*, liver; *f*, rudiment of Wolffian body; *g*, *g*, rudiments of extremities.

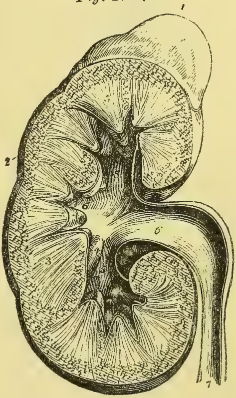
† Kidney of fœtal Boa:—the urinary tubes as yet short and straight.

‡ Portion of Kidney from Coluber:—*a*, *a*, vascular trunk; *b*, *b*, ureter; *c*, *c*, converging fasciculi of tubuli uriniferi.

into the ureter (Fig. 178). The bundles of tubuli and their vascular plexuses remain distinct, however, in Birds and in the lower Mammalia, so as to give to the whole gland a lobulated character; but in the Human Kidney (Fig. 179) they come into closer contact; and the vascular connection between the plexuses of the different bundles is such as to prevent any ostensible separation into distinct lobes.

Fig. 178.*

Fig. 179.†



728. The secreting apparatus of the Kidney consists of the *tubuli uriniferi* and of the epithelial cells by which they are lined. These, with the blood-vessels which supply the materials of the secretion, are imbedded in a 'stroma' composed of interlacing fibres, which is more abundant in the medullary than in the cortical substance, but which is condensed at the surface of the gland into a continuous membrane, which is loosely connected with the proper capsule. In passing outwards from the papillæ (Fig. 179, 4), the tubuli increase in number by divarication to a considerable extent (Fig. 181, H, H), their diameter remaining about the same. When they arrive at the cortical substance, they seem not only to become much convoluted, but also to form a sort of plexus with free extremities here and there; the number of such free extremities, however, does not seem to be nearly equal to that of the uriniferous tubes themselves. The character of the epithelium which

* Pyramidal fasciculi of Tubuli Uriniferi of Bird, terminating in one of the branches of the ureter.

† A section of the Kidney, surmounted by the Supra-Renal capsule; the swellings upon the surface mark the original constitution of the organ, as made up of distinct lobes:—1. The supra-renal capsule; 2. the cortical portion of the kidney; 3, 3, its medullary portion, consisting of cones; 4, 4, two of the papillæ projecting into their corresponding calices; 5, 5, 5, the three infundibula; the middle 5 is situated in the mouth of a calyx; 6. the pelvis; 7. the ureter.

lines the tubuli, varies in different parts of their course. In the tubes of the cortical substance, the cells are spheroidal in their

Fig. 180.*

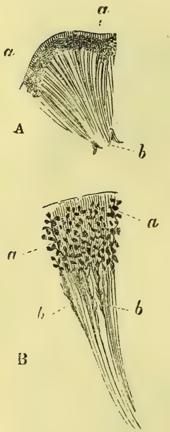
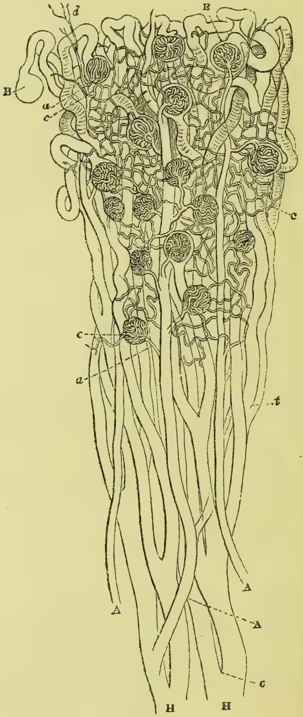


Fig. 181.†



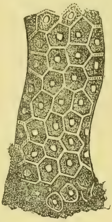
form, and project considerably into the cavity of the tube; but in the straight tubes of the medullary substance, the cells are flattened and polygonal (Fig. 182), and lie close against the wall of the tube. Each cell contains a nucleus; and in its interior there is ordinarily to be seen a little finely-granular matter, with a few

* Portion of the Kidney of a new-born infant:—A, natural size; *a, a,* Corpora Malpighiana, as dispersed points in the cortical substance; *b*, papilla. B, a smaller part magnified; *a, a*, Corpora Malpighiana; *b, b*, tubuli uriniferi.

† Plan of the structure of the Kidney:—A, A, primary branches of the renal artery; *a, a*, twigs proceeding to Malpighian bodies; B, B, Malpighian bodies; *c, c*, capillary network, partly formed by efferent vessels from Malpighian bodies, and partly by twigs, *d*, of the renal artery, which do not pass into them; H, H, larger tubuli uriniferi dividing dichotomously; *t*, a smaller tube.

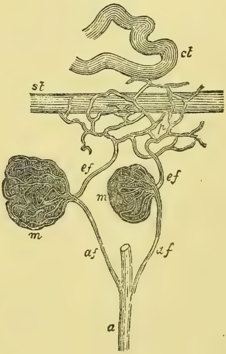
minute fat-globules clustered round the nucleus. The cell-wall is very thin; and there is strong reason to believe that it gives passage to the components of the urinary secretion, so that these are continually escaping into the tubes by transudation, without the death of the cells which secreted them.

Fig. 182.*



729. Besides its proper secreting structure, the Kidney contains an apparatus of a very peculiar description, which appears specially destined for the separation of the superfluous *fluid* of the system. When a section of the Kidney is slightly magnified (Fig. 180, B), the cut surface is seen to be studded by a number of little dark points; each of which, when examined under a higher magnifying power, is found to consist of a knot of minute blood-vessels, formed by the convolutions of thin-walled capillaries (Fig. 181, B, B). It has been shown by Mr. Bowman, that each one of these knots (called Malpighian bodies, after their discoverer) is included in a flask-like capsular dilatation, connected with one of the tubuli uriniferi; and that it is directly supplied by a branch of the renal artery (Figs. 181, *a*, *a*, and 183, *af*) which, upon piercing the capsule, subdivides into a group of capillaries; and these, after forming the convoluted tuft, coalesce into a single efferent trunk (*ef*), which may be considered as representing (in a small way) the vena portæ. For the efferent trunks of the Malpighian bodies discharge their blood into the capillary plexus (Fig. 181, *c*, *c*) which surrounds the tubuli uriniferi, and from which the solid matter of the urinary secretion is elaborated; just as the vena portæ supplies the capillary plexus from which the biliary secretion is elaborated in the liver. In Reptiles (in which, as in Fishes, the kidney is partly supplied by the hepatic portal system), the efferent vessels of the Malpighian bodies unite with

Fig. 183.†



* Epithelial lining of one of the Tubuli Uriniferi.

† Distribution of the Renal vessels, from Kidney of Horse:—*a*, branch of Renal artery; *af*, afferent vessel; *m*, *m*, Malpighian tufts; *ef*, *ef*, efferent vessels; *p*, vascular plexus surrounding the tubes; *st*, straight tube; *ct*, convoluted tube.

branches of the portal vein to form the secreting plexus around the tubuli uriniferi; and even in Birds this arrangement still seems to prevail to a certain extent. Thus all the blood which the secreting plexus receives, has already passed, in each case, through a set of capillaries within or without the organ; those, namely, of the Malpighian bodies, or those of the parts supplying the general Portal system.—The special purpose of the Malpighian bodies appears to be, to allow of the transudation of the *water* of the blood, which is filtered-off (so to speak) through the thin walls of their capillaries, and thus passes into the tubuli uriniferi. It is well known that the fluid and the solid constituents of the urinary secretion bear no constant relation to each other; the amount of fluid depending mainly upon the degree of fulness of the blood-vessels, whilst the amount of solid matter is proportionate, as we shall presently see, to the amount of azotized matter in the ingesta and to the previous *waste* of the tissues. The quantity of fluid in the blood-vessels is governed by the relative amount that has been absorbed and that which has been exhaled from the Skin; so that the quantity to be drawn-off by the kidneys is increased, either by augmented absorption, or by diminished exhalation. The Malpighian bodies seem to act the part of a system of regulating valves; permitting the transudation of only enough fluid to dissolve the solid matter, when there is no superfluity of water in the vessels; but allowing the escape of an almost unlimited amount of it, when increased imbibition has rendered the vessels unusually turgid. It appears, however, from the recent observations of Prof. Kölliker and Dr. Isaacs, that the Malpighian tufts do not lie loose and bare in their capsules, as was supposed by Mr. Bowman, but that they are covered with oval nucleated cells; and it is probable that these share the proper secretory function of the Kidney with the cells of the ordinary tubuli.

730. The average amount of Urine excreted in twenty-four hours, by adults who do not drink more than the wants of nature require, is probably from 40 to 50 oz.; and its average specific gravity may be about 1020. The quantity of fluid is usually less, and the specific gravity of the secretion consequently greater, in summer than in winter; on account of the larger proportion of fluid exhaled by the skin during the former season. The quantity of solid matter has been found to vary, within the limits of ordinary health, from 2 to 7 per cent.; this variation not being due so much to differences in the absolute amount of solid matter, as to fluctuations in the proportion of water. About one-third of the solid matter is made-up of alkaline and earthy Salts, and the remainder consists of Organic compounds. The Salts are partly those of the blood, which will be separated during the transudation of the serum through the membranous walls of the Malpighian

capillaries, although the albuminous matter is kept-back (§ 491); but there is a much larger proportion of the alkaline and earthy phosphates in the urine than is present in the blood, and this is liable to a further increase under circumstances to be presently alluded-to.—The Organic compounds present in the Urinary secretion (in its healthy state at least) are undoubtedly the result of the *waste* or disintegration of the animal fabric, as well as (in certain cases) of the decomposition of constituents of the blood which have never undergone conversion into organized tissue (§ 638). Their unfitness to be retained within the system, is proved by the fatal results which speedily ensue when their elimination by the secreting process receives a check; and also by the *crystalline* form in which the most characteristic of them present themselves,—such a form being altogether incompatible with the possession of plastic or organizable properties. Various well-defined compounds present themselves in the Urine of different classes of animals; and they are nearly all peculiarly rich in Nitrogen and deficient in Carbon, as compared with the Albuminous compounds. The chief exception is in the case of Hippuric acid; and the large proportion of carbon and the small proportion of nitrogen contained in this substance, appear due to the great excess of non-azotized compounds in the food of the animals voiding it in large quantity. The Colouring matter of the Urine is also remarkable for its very large proportion of carbon, and its low per-centage of nitrogen.

731. The Urine is normally acid, but the degree of its acidity is continually changing, and is considerably affected by food; being augmented by vegetable, and decreased by animal food. This is due to differences, not only in the amount of acid generated, but also in that of bases present to neutralize them. The ordinary acid reaction appears to be due, not to the presence of any free acid, but to the conversion of the *basic* phosphate of soda of the Blood into the *acid* phosphate, by the subtraction of a part of the base, which happens when uric, hippuric, lactic, or any other free acid comes into relation with it. Now a Herbivorous regimen supplies a large quantity of alkaline and earthy bases, in combination with citric, tartaric, oxalic, and other organic acids; these are reduced to the state of carbonates by the decomposition of their acids within the body; and the quantity of the sulphuric, phosphoric, and uric acids produced within the body (§ 737) not being sufficient to neutralize the bases, the urine has an alkaline reaction. On the other hand, a Carnivorous regimen supplies but a small quantity of the alkaline bases, and a large amount of acidifiable materials; so that, the acids produced in the system being more than sufficient to neutralize the bases, the urine has an acid reaction. Moreover, it has been shown by Dr. Bence Jones, that when the acidity of the stomach is at its maximum (which is the case soon after the ingestion of food), that of the urine decreases, so that, from three

to five hours after a meal, the urine is often alkaline; whilst, on the other hand, after a fast of some hours, when the acidity of the stomach is at its minimum, that of the urine is at its maximum.

732. Of the compounds just enumerated, the most important, in Man, is that which is named *Urea*. It exists in urine in a state of perfect solution; and may be readily separated from it in the form of transparent colourless crystals, which have a faint and peculiar but not urinous odour. In its ultimate composition it is identical with Cyanate of Ammonia, being made-up of 2 Carbon, 4 Hydrogen, 2 Nitrogen, and 2 Oxygen,—a formula much more simple than that of almost any other organic substance. It may be detected in the Blood to the amount of 4 parts in 10,000 of renal arterial blood, which is reduced to 2 parts in renal venous blood by the eliminating action of the kidneys; that action being doubtless favoured by its remarkable power of transuding through animal membranes. The amount of Urea in the urine is liable to very great variation, in accordance with the degree in which the disintegrating process has been taking-place in the solid fabric, and also in conformity with the amount of azotized matter which has been taken-in as food. The total daily excretion of Urea in adult well-fed males seems to average about 500 grains; but this average may be widely departed-from, on the side either of excess or diminution, according to the nature of the diet and the amount of exertion of body or mind (§ 639). A purely animal diet may raise it to 800 grains; while a purely vegetable diet may lower it to 350 grains, and a non-nitrogenous diet to 240 grains. It is interesting to observe that children of eight years old excrete, on the average, *half* as much Urea as adults; whilst, in very old persons, the quantity sinks to *one-third*, or even less. In proportion to their relative bulks, therefore, children excrete at least two or three times the quantity of urea that is set-free by adults, and four or five times that which is excreted by old persons;—a fact which corresponds with other indications of the far greater rapidity of interstitial change in the earlier periods of life, than in adult or advanced age.

733. The substance termed *Uric* or *Lithic Acid*, which is nearly allied to Urea in composition, but differs from it in its distinctly acid properties and also in its comparative insolubility, forms but a small proportion of the solid matter of Human urine in the state of health; but it is the chief component of the urine of the lower Vertebrata, and its presence in too large a proportion is a frequent symptom of disease in Man. Its ultimate composition is C^{10}, H^4, N^4, O^6; it crystallizes in fine scales of a brilliant white colour and silky lustre; and it is so sparingly soluble in water, that at least 10,000 times its own weight of fluid is required to dissolve it. It may be detected in minute quantity in healthy blood; and in

larger proportion in the spleen-pulp, also in the lungs, liver, pancreas and brain. In healthy Human urine, it is kept in solution by union with bases (soda or ammonia, or both), but it is precipitated by the addition of a small quantity of any acid, even the Carbonic.—The proportion of Uric acid in *healthy* urine seldom rises above 1 part in 1000; and the quantity excreted daily is usually from 6 to 10 grains. The circumstances under which it varies, however, have not been clearly determined; but it is certainly augmented by an animal diet, and reduced by restriction to vegetable food. The absolute quantity in the urine bears no proportion to its acidity, nor is it indicated by the amount of deposit; for the acidity of the urine depends upon the presence of other acids; and a deposit of urate of soda or ammonia may be due to an excess of acid, diminishing its solubility, rather than to an excess of the substance itself. Thus it may happen that such a precipitate may be formed when the urate is not present in any undue proportion, in consequence of the acid state of the urine; whilst, on the other hand, there may be a large excess of the urate in the urine without any precipitate, if the urine should be alkaline. The solubility of the urates of soda and ammonia is much greater in warm than in cold urine; and hence it frequently happens, that urine which is clear when voided, gives a precipitate on cooling. In disordered states of the system, there is often a great increase in the amount of Uric acid both in the Blood and in the Urine; and there can be no doubt that the increase is partly controllable by the reduction of the proportion of azotized matter in the food. In some of these cases, free uric acid is deposited in consequence of the decomposition of the urate of soda or ammonia by a large excess of acid in the urine. In attacks of gout, urate of soda is separated from the circulating blood, and is deposited in the tissues around the affected joints, forming the concretions termed 'chalk-stones;' and in this state of the system, an excess of uric acid may be detected in the blood. The production of uric acid in the body seems to be increased by any circumstances that interfere with the due oxidation of the azotized matters that are undergoing decomposition; hence such an increase may occur, either from deficient respiratory activity, or from an excess in the amount of the substances to be oxidated.

734. Although *Hippuric* acid was formerly supposed to be restricted to the urine of Herbivorous animals (in which it replaces uric acid), yet there is now no doubt of its being a normal component of the urine of Man. Its composition and properties are very different from those of uric acid. When pure, it forms long transparent four-sided prisms; it is soluble in 400 parts of cold water, and dissolves readily at a boiling heat; and it has a strong acid reaction, with a bitterish taste. It is composed of C^{18}, H^{8}, NO^{5}, with 1 equiv. of Water. A man living on a mixed

diet ordinarily excretes from 30 to 40 grains of this substance daily; but the quantity falls to about 12 grs. per diem on a purely animal diet, whilst it rises considerably when vegetables alone are consumed. The large proportion of Carbon in this substance, indicates that it is a product of imperfect oxidation: hence we can account, on the one hand, for its large amount in the urine of Herbivorous animals, whose food contains so large a proportion of substances requiring oxygen for their combustion; and, on the other, for its appearance in greatly-increased proportion in Human urine, when obstructed action in either of the other great emunctories throws upon the kidneys an unusually large proportion of carbonaceous matters for elimination.

735. It is a fact of peculiar interest, in regard to the sources of the peculiar excretory products of the Urine, that it should always contain the substance termed *Kreatinine;* which, with the allied substance *Kreatine*, is contained in the interstitial juices of Muscle (§ 338), and is pretty certainly one of the products of its retrograde metamorphosis; and which is also capable of conversion into Urea. Kreatinine is a crystallizable substance, readily soluble in water and in alcohol, and its composition is C^8, H^7, N^3, O^2; it has a distinctly alkaline reaction, being, indeed, the most powerful organic base in the body. The average amount of it daily eliminated by a healthy man living on a mixed diet seems to be about 15 grains. It has been supposed that Kreatine also is a normal constituent of the Urine; but late researches have shown that it is produced by the conversion of Kreatinine in the process used to separate it. Kreatine is a neutral crystalline substance, soluble in water, but only slightly soluble in alcohol; its formula is C^8, H^{11}, N^3, O^6, which is that of Kreatinine + 4 equiv. of Water. Kreatine can be readily converted, by boiling with baryta-water, into Urea and a crystalline substance termed Sarcosine; and it seems very probable that a similar conversion takes place in the living body, as one of the ordinary stages in the retrograde metamorphosis of Muscle-substance into Urea.

736. Of the substances ranked under the head of *Extractive Matters*, little is definitely known; it appears, however, from recent researches, that they are peculiarly rich in carbon, and that they are liable to be greatly augmented, either by an excess of non-azotized matter in the food, or by any impediment to the action of the liver or lungs. It has been pointed-out by Dr. Dalton that the urine contains some organic substance which interferes with the action of Iodine upon Starch, and with that of Trommer's test for Sugar; and it would not seem improbable that this substance may be *Albuminose* (§ 473), which, if received into the circulating current faster than it can be converted into Albumen, will be likely to find its way into the Urine in virtue of its great power of transudation (§ 492).—The *Urine-pigment*

seems to be distinguishable as a definite compound, related to the Hæmatin of the Blood; it contains a very large proportion of Carbon. The action of hydrochloric acid on this pigment produces the substance called *purpurine*, which sometimes gives a deep colour to the sediment of urate of ammonia. A *Sulphur-extractive* has also been obtained from the urine, in which (as in the bile) there is a considerable proportion of free sulphur; and sometimes there is enough unoxidized Phosphorus in the urine to render it luminous (§ 770).

737. The Urine also contains a considerable amount of *Saline* matter, of which the acids as well as the bases are derived from the mineral kingdom; and the excretion of them, after they have served their purpose in the economy, appears to be one of the chief functions of the Kidney. Of these, a part may find their way directly into the urine from the serum of the blood, when its water is being filtered-off (so to speak) through the walls of the Malpighian capillaries. This is probably the chief source of the large quantity of the chlorides of sodium and ammonium contained in the urine. But the urinary secretion seems to be specially destined to eliminate those saline compounds which are formed by the acidification of the Sulphur and Phosphorus taken in with the albuminous compounds as food. These substances are united with Oxygen in the system, and are thus converted into Sulphuric and Phosphoric acids; which acids unite with alkaline bases that were ingested in combination with Citric, Tartaric, Oxalic, and other organic acids; the latter undergoing decomposition within the system, and leaving their bases ready to unite with others. The Sulphur destined to elimination appears to be separated in the first instance in the tauro-cholic acid of the Bile (§ 724); and then, being in great part re-absorbed into the current of the circulation, to be subsequently oxidized into Sulphuric acid.

738. The Alkaline *Sulphates*, whether taken-in as such, or formed in the manner now described, are soluble enough to be always passed-off in the fluid form; and this is normally the case with the *Phosphates* also. In fresh healthy urine, the Phosphates of Lime and Magnesia, derived from the Blood, though insoluble, or nearly so, in pure water, are held in complete solution by the acid Phosphate of Soda; and they remain so as long as the latter salt retains its preponderance of acid (§ 731). If, however, this should be neutralized by the addition of Ammonia, a deposit of the Earthy Phosphates takes-place, and if the ammonia be in excess, it enters into combination with the phosphates of magnesia and soda, forming 'triple phosphates,' which are deposited in a crystalline form. This process takes-place normally during the decomposition of the urine (§ 740); and a similar deposit of Earthy and Alkaline Phosphates may occur in Urine almost immediately on its being passed, if it have an alkaline reaction.

The most common cause of 'alkaline urine' is the retention of the fluid in the bladder in consequence of paralysis, which is usually accompanied with an excessive secretion of mucus; so that the 'alkaline fermentation' of the Urine is already in progress when the fluid is voided.

739. But it seems probable that the cause of such deposits occasionally lies in an excessive production of the Phosphatic salts, arising from the increased waste or disintegration of Nervous matter, which takes-place when the Nervous system is in a state of unusual activity, either from intense thought, from prolonged exertion, or from continued activity (§§ 384, 386). In the oxygenation which seems to be an essential condition of the functional activity of the Nervous system, Phosphoric acid will be produced, owing to the large amount of phosphorus contained in the nervous matter; and this will unite in part with ammonia, which is perhaps set-free by the same metamorphosis, or is derived from other sources; and in part with the fixed alkalies derived from the food.

740. In all healthy Urine there is present a small amount of *Mucus*, which is secreted by the lining membrane of the Urinary bladder; this is so diffused through the liquid when first discharged, as not to interfere with its transparence; but if the Urine be allowed to remain at rest for some hours in a cylindrical glass vessel, the Mucus collects at the bottom, forming a light cottony cloud often interspersed with minute semi-opaque points. The decomposition which this Mucus undergoes, with a rapidity proportioned to the elevation of the temperature at which the liquid is kept, is very important as influencing the state of the proper components of the Urine, upon which it acts as a *ferment*. The first change of this kind occurs within from 12 to 48 hours (according to the temperature) in some of the 'ill-defined principles' contained in the Extractive; and consists in the development of *free acids*, usually the *lactic* and the *oxalic*. Both these acids have been so frequently recognized in nearly fresh Urine, that some eminent Chemists have regarded them as normal or at least occasional constituents of the excretion. It appears, however, from recent careful enquiries, that Lactic acid does not show itself until there has been time for its development by the 'acid fermentation' of the Urine: and that unless the presence of Oxalic acid should depend upon the existence of that acid (either in a free or in a combined state) in the food, its formation takes place under the same conditions. The production of Lactic acid occasions a deposit of free lithic acid (§ 733); on the other hand, as Oxalic acid cannot be generated in the presence of Lime without combining and precipitating with that base, minute octohedral crystals of Oxalate of Lime very commonly show themselves about the beginning of the second day, in the cloud of cottony

Mucus which collects at the bottom of the vessel, the supernatant fluid remaining clear.—After an interval of some days, the Mucus having passed into a state of more advanced decomposition, an 'alkaline fermentation' takes-place in the Urine; a large quantity of Carbonate of Ammonia being generated by the decomposition of the Urea (§ 197). The gradual production of this Ammoniacal salt first diminishes the acid reaction of the Urine, then renders the liquid neutral, and then gives it an alkaline reaction; and this first shows itself in the precipitation of the Earthy phosphates previously held in solution by excess of phosphoric acid (§ 738), this precipitate being amorphous, and slowly settling upon the sides and bottom of the vessel. A further liberation of Carbonate of Ammonia gives-rise to the formation of two double salts; one, known as the 'triple phosphate,' being the Phosphate of Magnesia and Ammonia, while the other is the Phosphate of Soda and Ammonia. The 'triple phosphate' deposits itself in colourless and transparent crystals, having the form of triangular prisms, which show themselves throughout all parts of the mixture; growing gradually in the mucus at the bottom, adhering to the sides of the glass, and scattered abundantly over the film which collects on the surface, to which they give a peculiar glistening and iridescent appearance. With these are mingled the crystals of the Phosphate of Soda and Ammonia, which are distinguished by the form of their prisms, this being either quadrangular or derived from the quadrangular.—As the alkaline fermentation of the Urine continues, Carbonate of Ammonia is given-off in such quantity as to give it a strongly ammoniacal smell; and the process continues until the Urea has been entirely decomposed.*

741. The total suspension of the Urinary secretion is productive of rapidly-fatal results, from the accumulation of the elements of the secretion in the blood; and it would appear that the tissue on which their presence in the circulating fluid exerts the most injurious effects, is the Nervous. It is probable that Urea is the substance which is most directly concerned in producing the noxious influence; though as the severity of the symptoms does not bear any proportion to the degree in which the blood is charged with it, there is reason to believe that it must undergo some change by decomposition (perhaps into Carbonate of Ammonia) in order to produce a poisonous effect. We see an effort made by the system (so to speak) to get rid of retained urea, in those cases in which a discharge of urinous fluid takes-place by unusual channels, such as from the mucous membrane of the stomach, the mamma, the umbilicus, the nose, &c., when the usual secreting action of the kidney has been suspended. This is readily understood when

* The above paragraph is an abridgment of the excellent section on the Changes in the Urine during Decomposition in Dr. Dalton's "Human Physiology."

the peculiar transuding power of Urea is borne in mind; of which power we have another illustration in the effusions containing urea, which have been found in the serous cavities of the trunk and in the ventricles of the brain of persons who have died from *Uræmia*, that is, from the poisoning of the blood resulting from the complete suspension of the secretion. The poisonous influence when strongly exerted produces in the first instance irregular or convulsive movements, which are dependent upon irritation of the Spinal system of nerves; then loss of consciousness, depending upon the suspension of the powers of the Brain; and lastly, complete suspension of the powers of the spinal system, so that the ordinary Reflex actions cease, and life becomes extinct from the stoppage of the respiratory movements (§ 688). There is reason to believe that many convulsive motions for which no obvious cause can be assigned, have their origin in a disordered condition of the blood resulting from imperfect elimination of Urea; thus it has been ascertained that in several cases of puerperal convulsious urea was present in the blood, the functional power of the kidney being diminished by chronic disease. It is especially to be noticed, that most of the cases in which the urinary secretion is discharged through some irregular channel, occur in persons who have been subject to those convulsive affections which are commonly designated as *hysterical;* and that the discharge of a large quantity of urine through the natural channel is often the termination of an hysterical paroxysm. It is desirable, therefore, that in all such obscure cases the state of the urinary secretion should be carefully looked-to.

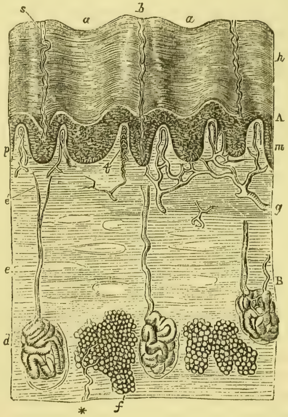
4. *Of the Cutaneous and Intestinal Glandulæ.*

742. The Glandulæ which are disposed in the substance of the Skin and in the walls of the Intestinal canal, although individually minute, make-up by their aggregation an excreting apparatus of no mean importance. The Skin is the seat of two processes in particular; one of which is destined to free the blood from a large quantity of fluid; and the other to draw-off a considerable amount of solid matter. To effect these processes, we meet with two distinct classes of glandulæ in its substance; the Sudoriparous or sweat-glands, and the Sebaceous or oil-glands. They are both formed, however, upon the same simple plan; and can frequently be distinguished only by the nature of their secreted product.

743. The *Sudoriparous* or Perspiratory glandulæ form small oval or globular masses, situated in the deepest layer of the cutis, in almost every part of the surface of the body (Fig. 184, *d*). Each is formed by the convolution of a single tube; which thence runs towards the surface as the efferent duct, making numerous spiral turns in its passage through the epidermis, and issuing from

its surface rather obliquely, so that its orifice is covered by a sort of little valve of scarf-skin, which is lifted-up as the fluid issues from it. The convoluted knot of which the gland consists, is copiously supplied with blood-vessels. On the palm of the hand, the sole of the foot, and the extremities of the fingers, the apertures of the perspiratory ducts are visible to the naked eye, being situated at regular distances along the little ridges of sensory papillæ, and giving to the latter the appearance of being crossed by transverse lines. According to Mr. Erasmus Wilson, as many as 3,528 of these glandulæ exist in a square inch of surface on the palm of the hand; and as every tube, when straightened-out, is about a quarter of an inch in length, it follows that in a square inch of skin from the palm of the hand, there exists a length of tubing equal to 882 inches, or $73\frac{1}{2}$ feet. The number of glandulæ in other parts of the skin is sometimes greater but generally less than this; and according to Mr. Wilson, about 2,800 may be taken as the average number of pores in each square inch throughout the body. Now the number of square inches of surface, in a man of ordinary stature, is about 2,500; the number of pores, therefore, is *seven millions;* and the number of inches of perspiratory tubing would thus be 1,750,000, or 145,833 feet, or 48,611 yards, or nearly *twenty-eight miles.*

Fig. 184.*



744. From this extensive system of glandulæ, a secretion of watery fluid is continually taking-place; and a considerable amount of solid matter also is drawn-off by the epithelium-cells that line the tubuli. Under ordinary circumstances, the fluid is carried-off in the state of vapour, forming the *insensible* perspira-

* Vertical Section of Skin of Finger:—A, Epidermis, the surface of which shows hollow depressions, *a a*, between the papillary eminences, *b*, and the openings of the perspiratory ducts, *s;* at *m* is seen the deeper layer of the epidermis, or stratum Malpighii;—B, Cutis Vera, in which are imbedded the perspiratory glands, *d*, with their ducts, *e*, and also aggregations of fat-cells, *f;* at *g* is seen an arterial twig supplying the vascular papillæ, *p;* and at *t* one of the tactile papillæ with its nerve.

tion; and it is only when its amount is considerably increased, or when the surrounding air is already so loaded with moisture as to be incapable of receiving more, that the fluid remains in the form of *sensible* perspiration upon the surface of the skin. It is difficult to estimate the proportion of solid matter contained in this secretion; partly on account of the great variations in the amount of fluid eliminated by the Sudoriparous glands, which are governed by the temperature of the skin; and partly because the secretion can scarcely be collected for analysis, free from the sebaceous and other matters which accumulate on the surface of the skin. According to Anselmino, the proportion of solid matter varies from $\frac{1}{2}$ to $1\frac{1}{2}$ per cent: and it consists in part of Epithelial scales from the lining of the gland-tubes; in part of certain volatile Acids, as the acetic, butyric, formic, and capric, to which the acid reaction and sour smell of the secretion are due; and in part of Saline matters, directly proceeding from the serum of the blood. Urea has also been detected in the perspiration, especially in that of the inhabitants of warm climates; no exact estimate, however, has yet been formed of its daily amount.

745. The quantity of fluid excreted from the Skin is almost entirely dependent upon the *temperature* of the surrounding medium; being increased with its rise, and diminished with its fall. The *object* of this variation is very evident; being the regulation of the Temperature of the body. When the surface is exposed to a high degree of external heat, the increased amount of fluid set-free from the perspiratory glands becomes the means of keeping down its own temperature; for this fluid is then carried off in a state of vapour as fast as it is set-free, and in its change of form withdraws a large quantity of caloric from the surface. But if the hot atmosphere be already loaded with vapour, this cooling power cannot be exerted; the temperature of the body is raised; and death supervenes if the experiment be long continued. The *cause* of the increased secretion is probably to be looked-for in the increased determination of blood to the skin, which takes place under the stimulus of heat.—The entire loss by Exhalation from the lungs and skin, during the twenty-four hours, seems to average a little above 3 lbs. In a warm dry atmosphere, however, it has been found to rise to as much as 5 lbs.; whilst in a cold damp one, it may be lowered to $1\frac{2}{3}$ lb. Of this quantity, the pulmonary exhalation is usually somewhat less than one-third, and the cutaneous somewhat more than two-thirds; but when the quantity of fluid lost is unusually great, the increase must be chiefly in the Cutaneous exhalation; since, as already pointed out (§ 701), the amount of exhalation from the lungs is not influenced by the external temperature, but only by the degree in which the surrounding air is previously saturated with moisture.

746. The variations in the amount of fluid set-free by Cutaneous and Pulmonary Exhalation, are counterbalanced by the regulating action of the Kidney (§ 729); which allows a larger proportion of water to be strained-off in a liquid state from the blood-vessels, as the Exhalation is less,—and *vice versâ*. The Cutaneous and Urinary excretions seem to be vicarious, not merely in regard to the amount of fluid which they carry-off from the blood, but also in respect to the solid matter which they eliminate from it. It appears that at least 100 grains of effete azotized matter are daily thrown off from the Skin; and any cause which checks this excretion must increase the labour of the Kidneys, or produce an accumulation of noxious matter in the blood. Hence attention to the functions of the skin, at all times a matter of great importance, is peculiarly required in the treatment of Urinary diseases; and it will be often found that no means is so useful in removing the lithic acid deposit, as copious ablution and friction of the skin, combined with exercise. When the exhalant action of the Skin is completely checked by the application of an impermeable varnish, the effect is not (as might be anticipated) an elevation of the temperature of the body; on the contrary it is lowered, in consequence, as it would appear, of the interruption to the aëration of the blood through the skin, which is a function of such importance in the lower animals (§ 671), and of no trifling account in Man; and in a short time, a fatal result ensues. A partial suppression by the same means gives rise to febrile symptoms, and to Albuminuria, or escape of the albuminous part of the liquor sanguinis into the urinary tubes, in consequence (it would appear) of the increased determination which then takes-place towards the Kidneys. These facts are interesting, as throwing light upon the febrile disturbance that accompanies those Cutaneous diseases which affect the whole surface of the skin at once, and interfere with its functions; and as partly accounting also for the Albuminuria which frequently manifests itself during their progress, especially in Scarlatina. The peculiar poison of the last-named disease, however, seems to have a special action on the tubuli uriniferi, occasioning a desquamation of their epithelium, as it does of the cutaneous epidermis.

747. The Skin is likewise furnished with numerous *Sebaceous* glands, which are distributed more or less closely over the greater part of the surface of the body; being most abundant on parts most thickly covered with hair, and least numerous where the hair is scanty; whilst they are altogether absent in parts which have no hair, such as the palms of the hands and soles of the feet, on which the Perspiratory glands are most numerous. They differ greatly in size and in degree of complexity; sometimes consisting of short straight follicles; sometimes closely resembling the Sudo-

riparous glandulæ, the tubes, however, being usually straighter and wider; and being sometimes much more complex in structure, consisting of a number of distinct sacculi clustered round the extremity of a common duct into which they open, and forming little arborescent masses about the size of millet-seeds. In the hairy parts of the skin, we usually find a pair of Sebaceous follicles opening into the passage through which every hair ascends. In some situations they acquire still greater complexity. Thus the Meibomian glandulæ, which are found at the edges of the eyelids, and which secrete an unctuous matter for their lubrication, are long sacculi branching out at the sides (Fig. 161); and the glandulæ of the ear-passage, which secrete its cerumen or waxy matter, and which belong to the general Sebaceous system, are formed of long tubes, highly contorted, and copiously supplied with blood-vessels. The purpose of the sebaceous secretion is evidently to prevent the skin from being dried and cracked by the influence of the sun and air. It is much more abundant in those races of mankind which are formed to exist in warm climates, than in the races that naturally inhabit cold countries; and the former are accustomed to aid its preservative power, by lubricating their skin with vegetable oils of various kinds; which process they find to be of use in protecting it from the scorching influence of the solar rays.—The Sebaceous follicles, especially in the face, are frequently the residence of a curious parasite, the *Demodex folliculorum*, which is stated by Mr. Erasmus Wilson to be present in great numbers in the skin of almost all inhabitants of large towns; the activity of their cutaneous glandular system being much checked by the want of free exposure to pure air, and by inert habits of life.

748. The function of the Skin as a channel for the elimination of effete matters from the blood has been probably much underrated; and much more use might be made of it in the treatment of diseases,—especially of such as depend upon the presence of some morbific matter in the circulating current,—than is commonly thought advisable. We see that Nature frequently uses it for this purpose; a copious perspiration being often the turning-point or 'crisis' of febrile diseases, removing the cause of the malady from the blood, and allowing the restorative powers free play. Again, certain forms of Rheumatism are characterised by copious acid perspirations; and instead of endeavouring to check these, we should rather encourage them, as the best means of freeing the blood from its undue accumulation of lactic acid. And it is recorded that in the 'sweating sickness,' which spread throughout Europe in the 16th century, no remedies seemed of any avail but diaphoretics; which, aiding the powers of nature, concurred with them them to purify the blood of its morbific matter. The hot-air bath, in some cases, and the wet sheet (which, as used by

the Hydropathists, is one of the most powerful of all diaphoretics), will be probably employed more extensively as therapeutic agents, in proportion as the importance of acting on the Skin, as an extensive collection of glandulæ, comes to be better understood. The empiricism of the 'Hydropathic system' consists in the indiscriminate application of the treatment to a great variety of diseases; no person who has watched its operation, can deny that it is a remedy of a most powerful kind; and if its agency be fairly tested, there is strong reason to believe, that it will be found to be one of the most valuable curative means we possess for various specific diseases which depend upon the presence of a definite *materies morbi* in the blood, especially Gout and Chronic Rheumatism ; as well as for that depressed state of the general system, which results from the 'wear and tear' of the bodily and mental powers.

749. The Mucous surface of the Alimentary Canal is furnished, like the skin, with a vast number of glandulæ, varying in complexity from the simple follicle, to a mass consisting of numerous lobules opening into a common excretory duct. The functions of these, as already pointed-out (§§ 449, 450), are equally various. There is strong reason to believe that the function of the glandulæ which beset the walls of the lower part of the Intestinal canal, is purely excretory; and that they are destined to eliminate putrescent matters from the blood, and to convey them by the readiest channel completely out of the body. That the putrescent elements of the fæces are not immediately derived from the food taken-in, so much as from an excretory process, appears from this consideration; — that fæcal matter is still discharged, even in considerable quantities, long after the intestinal tube has been completely emptied of its alimentary contents. We see this in the course of many diseases, when food is not taken for several days, during which time the bowels are completely emptied of their previous contents by repeated evacuations; and whatever then passes must be derived either from the intestinal walls themselves, or from the glands that discharge their contents into the cavity. Sometimes a copious flux of putrescent matter continues to take place spontaneously; whilst it is often produced by the agency of purgative medicine. The 'colliquative diarrhœa,' which frequently comes-on at the close of exhausting diseases, and which usually precedes death by starvation, appears to depend, not so much upon a disordered state of the intestinal glandulæ, as upon the general disintegration of the solids of the body, which calls those glandulæ into extraordinary activity for the purpose of separating the decomposing matter.

750. Thus we perceive that we have here, also, to watch for the indications of Nature; and that this extensive system of Intestinal glandulæ, being the principal channel for the elimination

of putrescent matters from the blood, should be especially attended-to, when there is reason to think that such matters are present in too large an amount. Hence, when diarrhœa is already existing, we may often do more good by allowing it to take its course, or even by increasing it by the agency of mild purgative medicines, than by attempting to check it, and thus causing the retention of the morbid matter in the circulating current. But, on the other hand, it is necessary to bear in mind the extreme irritability of the intestinal mucous membrane; and carefully to avoid exciting it when it is already in excess, or when there is danger that it will supervene,—as in that form of Fever in which there is a peculiar liability to inflammation and ulceration of the walls of the alimentary canal and of their contained glandules.

5. *General Summary of the Excreting Processes.*

751. We have now passed in review the various processes by which the products of the disintegration of the animal tissues are carried-off; and we have seen that the necessity for their removal is much more urgent than for the replacement of the substances from which they proceeded. A cold-blooded animal may subsist for some weeks or even months without a fresh supply of food, the waste of its tissues being so small, if it remain in a state of rest, as to be quite compatible with the continuance of its life; and a warm-blooded animal may live for many days or even weeks, provided that it has in its body a store of fat sufficient to keep-up its heat by the combustive process. But in either case, if the exhalation of carbonic acid by the Lungs, the elimination of biliary matter by the Liver, the separation of urea or uric acid by the Kidneys, or the withdrawal of putrescent matter by the Intestinal glandulæ, be completely checked, a fatal result speedily ensues;—more speedily in warm-blooded animals than in those which cannot sustain a high independent temperature, on account of the greater proneness to decomposition in the bodies of the former than in those of the latter;—and more speedily in the latter when their bodies are kept at an elevated temperature by the warmth of the surrounding medium, than when the degree of heat is so low that there is little proneness to spontaneous change in the substance of their bodies.

752. It may be taken as a general principle, in regard to the Excreting processes (including Respiration), that they have a three-fold purpose;—in the first place, to carry-off the *normal* results of the waste or disintegration of the solid tissues, and of the decomposition of the fluids;—in the second place, to draw-off the superfluous alimentary matter, which, though received into the circulating current, is not converted into solid tissue in consequence of the want of demand for it; —and in the third place,

to carry-off the *abnormal* products, which occasionally result from irregular or morbid changes in the system. Thus by the Lungs are excreted a large amount of carbon and some hydrogen, resulting from the disintegration of the tissues, especially the nervous and muscular; the same elements, in animals that take in a large proportion of farinaceous or oleaginous aliment, may be derived immediately from the food, without any previous conversion into solid tissue; and the respiratory function is also an important means of purifying the blood from various deleterious matters, either introduced from without (such as alcohol, chloroform, prussic acid, and other volatile poisons), or generated within the body (such as the poison of fever).* And it is important to bear this last circumstance in mind; since it enables us to understand how, if *time* be given, the system *frees itself* from such noxious substances; and points-out the duty of the medical attendant to be rather that of supporting the powers of the body by judiciously-devised means, and of aiding the elimination of the morbid matter through the Lungs and Skin by a copious supply of pure air, than of interfering more actively to promote that which Nature is already effecting in the most advantageous manner.

753. In like manner, the Liver is charged with the separation of *hydrocarbon* in a fluid form; for which a supply of oxygen is not requisite. This product is partly derived from the waste of the system; but the arrangement of the biliary vessels leads to the belief, that part of it may be at once derived from crude matter taken-up by the mesenteric veins, and eliminated from them by the hepatic cells without ever passing into the general circulation. And various facts seem to indicate that the Liver is also destined to remove from the blood extraneous substances which are noxious to it. Thus, in cases where death has resulted from the prolonged introduction of the salts of Copper into the system, a considerable amount of that metal has been obtained from the substance of the gland.

754. It has been already pointed out (§ 725), that in those tribes of animals whose respiration is feeble, a considerable part of the mass of the Liver is composed of Fatty matter; and this condition may be induced, as a state of disease, in warm-blooded energetically

Fig. 185.†

* There is strong reason to believe that, in many instances, a small amount of poisonous matter introduced from without, in the form of a contagion or miasm, may lead, by a process resembling fermentation, to the production of a large quantity of similar noxious substances in the animal fluids.

† Hepatic Cells gorged with Fat:—*a*, atrophied nucleus; *b*, adipose globules.

respiring Birds and Mammals, by impediments to the due performance of the respiratory process. This is remarkably shown in the treatment of the geese which are to furnish the celebrated Strasburg *pâtés*. The unfortunate bird is closely confined at a high temperature, so that the respiration is reduced to its minimum amount by the combined effects of warmth and muscular inaction; and it is then crammed with maize, which contains a large amount of oily matter. The consequence is, that its liver soon enlarges and becomes unusually fatty; its cells being gorged with oil-globules, instead of each containing no more than one or two; and it is then ready for the epicureans who set so high a value on the *pâté de foie gras*. A similar diseased condition of the liver frequently presents itself in Man, in connexion with chronic disorders of the respiratory organs, which diminish the amount of hydrocarbon eliminated through their agency; this 'fatty liver' (Fig. 186) is peculiarly common in the advanced stages of Phthisis. It may arise, however, from a local disorder of nutrition, such as that which produces the *fatty degeneration* of other organs. But this fatty degeneration, which usually commences with an increase in the proportion of fat in the blood, may itself be attributed to a disproportion between the amount of that substance in the circulating current, and the rate of the oxygenating process by which it is eliminated. Generally speaking, it depends upon some want of activity in the general habits, which keeps down the respiration to too low a standard; and it is a very common disorder among elderly persons, whose energy has not been sustained by adequate bodily exercise. But another most frequent cause is the habitual presence of Alcohol in the circulating current, the blood of drunkards being found to contain an enormous amount of fatty matter; and hence it may be fairly presumed that a proportional retardation will occur in the normal consumption of fat, even in the case of those who make use of the same substance to a less excessive amount.

755. With regard to the Kidneys, it has been already pointed out that they are the special emunctories of the *azotized* products of the decomposition of the tissues; and that they serve also to convey-away the overplus of such earthy and alkaline salts as are readily soluble. Moreover, it has been shown that the surplus albuminous compounds, which are not required for the nutrition of the system, must be excreted by their agency, after having been metamorphosed into urea. And we have now to notice that other matters of an injurious character, whether introduced from without, or generated within the system, are drawn-off by the same channel. Thus the saline compounds taken-up by the absorbent process are for the most part set-free through these organs; especially when their properties are such as to excite the action of the kidneys in a peculiar degree. We have

seen (§ 492) that ferrocyanide of potassium has been detected in the urine within one minute after it had been introduced into the stomach. Iodine, in all its combinations, is very speedily eliminated by the same channel; and vegetable alkaloids medicinally or experimentally administered, as quinine, morphine, strychnine, &c., may also be detected in the urine,—the eliminatory action of the Kidneys being in fact the chief means of preventing the violent action which would result from their accumulation in the body. Further, it has been shown that poisonous substances (such as arsenious acid), which tend to accumulate when introduced into the system in small but frequently-repeated doses, may be carried out of the body with such rapidity as to be prevented from exerting their injurious effects, provided that diuretics be administered at the same time. So, again, when lead-poisoning has arisen from the continual introduction of small quantities of that metal, which is deposited in almost all the soft tissues of the body, it is most effectually cured by the administration of Iodide of Potassium, which at the temperature of the blood has a solvent power for the metal, and which by its diuretic character specially determines it to the Kidneys, by whose agency it is finally eliminated.—The effect of the inhalation of the vapour of turpentine, even in a very diluted state, in speedily imparting to the urine the odour of violets, is an evidence that not merely the actual substances imbibed, but new and peculiar compounds to which they give-rise, are thus eliminated by the Kidneys.

756. The most singular variations in the excretory function of the Kidneys are seen, however, when the Urine is charged with substances which are not only foreign to it, but are altogether foreign to the healthy body. The most remarkable instance of this presents itself in Diabetes, in which a large quantity of Sugar is formed, either directly from the food, or by the disintegration of the solid tissues; and in which this compound is eliminated by the Kidneys, imparting to the urine a saccharine taste. And another example of the same general fact is seen in the 'oxalic diathesis,' in which an unusual arrangement of the elements that usually form urea or uric acid, gives-rise to a new and peculiar compound, Oxalate of ammonia; and this being drawn-off by the kidneys, and being decomposed by the calcareous matter present in the urine, occasions a deposit of Oxalate of lime.—In the treatment of such diseases, our attention must be given, not so much to the secreting organ, as to the condition of the system at large, of which the character of the secreted product is the indication or exponent.

757. To what has already been stated in regard to the exhalant functions of the Lungs and Skin, it may be added that many states of disease are marked by an unusual odour emitted from the body; and there can be little doubt that the peculiar odorous

matter is pre-formed in the blood; since we know that the ordinary scent of any species (whether Man, Dog, Horse, Goat, &c.) may be set-free from the blood of that species by the addition of sulphuric acid. The existence of such odours, therefore, is not to be attributed to disordered function in the excreting organs; but to the formation of morbid products in the interior of the body, which these organs do their best to remove. The fœtid breath which frequently accompanies an attack of indigestion, is another instance of the power of the lungs to eliminate, not merely carbonic acid, but other products of those changes in composition which the food undergoes when introduced into the system.

758. The same remarks apply, and with yet greater force, to the Intestinal glandulæ; whose function it is, not merely to remove the putrescent matter ordinarily formed by the disintegration of the tissues or by the decomposition of unassimilated food, but also to draw-off the still more offensive products of such changes as take place in disease. Thus there are conditions of the system, in which, without any well-marked disorder, the fæces emit a peculiar fœtid odour; and with these there is almost always associated a depressed state of mind. Now it can scarcely be doubted, that the real fault is here rather in the early part of the nutritive operations, than in the excretory function; and that the fœtor of the contents of the intestine depends upon the undue formation of putrescent matter in the system, which, by tainting the blood, causes its action upon the brain to become unhealthy. The object of the physician will be here to eliminate the morbid product by the moderate use of purgatives; and so to regulate the diet and regimen as to correct the tendency to its formation.—An excessive fœtor in the evacuations, as well as in the exhalations from the skin and lungs, is peculiarly characteristic of those very severe forms of typhus (now, happily, of comparatively rare occurrence), which are termed *putrid fevers*. Here the whole of the solids and fluids of the body appear to have an unusual tendency to decomposition, in consequence of the introduction of some morbid agent which acts as a *ferment;* and the system attempts to free itself from the products of that decomposition by the various organs of excretion, particularly the Skin and Intestinal surface.

759. It is of great importance that the Medical Practitioner should form clear conceptions on this subject; and that he should not (as too often happens), by directing his remedies to the mere symptoms or results of a disease, act in precise opposition to the natural tendency of the system to free itself from some unusual noxious matter, through those channels which are ordinarily destined to carry-off only the regular products of its disintegration.

CHAPTER XI.

OF THE DEVELOPMENT OF HEAT, LIGHT, AND ELECTRICITY, IN THE ANIMAL BODY.

760. It has been shown, in an earlier part of this volume (CHAP. II.), that *all* Vital actions require a certain amount of HEAT for their performance; and that there is a great variety amongst the different classes of Animals, both in regard to the degree of Heat which is most favourable to the several processes of their economy, and in regard to their own power of sustaining it, independently of oscillations in the temperature of the surrounding medium. As a general rule, the Invertebrated animals are *cold-blooded;* that is, they have little or no power of sustaining an independent temperature. The degree of energy of their vital actions entirely depends, therefore, upon the warmth they receive from the air or water they inhabit; they have no power of resisting the depressing influence of cold; and they are generally so organized as to pass into a state of complete inaction or torpidity, when the temperature sinks below a certain point, after gradually becoming more and more inert with every diminution in the heat of their bodies. The same is true, also, of most Fishes and Reptiles: but the animals of the former class, from the more equable temperature of the medium they inhabit, are not so liable to be reduced to inaction as the latter; being usually so organized as to retain their activity so long as the water around them continues liquid; and being actually imbedded in a frozen state, when the water around them is converted into ice, without the loss of their vitality. There are certain Fishes, however,—such as the Thunny, Sword-fish, and other large species of the Mackerel tribe,—which are able to maintain a temperature considerably above that of the sea they inhabit; thus in the Bonito, the heat of the body has been found to be 99° when the temperature of the surrounding sea was but 80½°. It is not probable, however, that the temperature of the body would be kept-up to the same standard, if that of the sea should be considerably lowered; but it would probably remain at from 18° to 20° above the latter. And in like manner, it has been noticed that many of the more active Reptiles possess the power of sustaining the temperature of their bodies at 10° or 15° above that of the surrounding air; this power being specially remarkable in such as incubate their eggs. Thus in the Python which recently went through that process in the Zoological Gardens, the temperature to which the eggs were subjected in the coils of the body wound round them averaged 90°, while that of the surrounding air was 60°.

761. The classes of animals which are especially endowed with the power of producing and maintaining heat, are Insects, Birds, and Mammals. The remarkable variations which present themselves in the temperature of the first of these classes, and the connection of these variations with the condition of the animals in regard to activity or repose, have already been sufficiently noticed (§ 123).—The temperature of Birds is higher than that of any other class of animals; varying from 100° to 111° or 112°. The lowest degree is found in some of the aquatic species, as the Gull, and in those which principally live on the ground, as the Fowl tribe; and the highest in the birds of most active flight, as the Swallow. The temperature of Mammals seems to range from about 96° to 104°; that of Man has been observed as low as 96½°, and as high as 102°, the average being probably 100°. The variations are dependent in part upon the temperature of the external air; but are influenced also by the general condition of the body as to repose or activity, the period of the day, the time that has elapsed since a meal, &c. A somewhat larger amount of caloric is generated during the day than in the night; and the body is usually warmer by a degree or two, at noon, than at midnight. There is also a slight increase during the digestion of a meal; and exercise is a powerful means of raising the temperature.—The range of temperature is much greater in disease; thus the thermometer has been seen to rise to 106° in Scarlatina and Typhus, and to 110¾° in Tetanus; whilst it has fallen to 82° in Spasmodic Asthma, and to 77° in Cyanosis and Asiatic Cholera. It is a very remarkable fact that the heat of the body sometimes increases after death, so as not merely to reach the natural standard where there has been previous depression (as in Cholera), but even to rise considerably above it; an elevation as high as 112° having been observed some hours after death from Yellow Fever.

762. In searching for the conditions on which this production of heat within the Animal body is dependent, it is very important to bear in mind that a similar generation of Caloric may be observed in the Vegetable kingdom. It appears from the most recent and exact experiments, that all *living* Plants are somewhat warmer than similar *dead* plants exposed to the same atmosphere; and that the elevation is the greatest in the leaves and young stems, in which the most active vital changes are taking place. But the most decided production of heat occurs in the *flowering* of certain Plants, such as the Arum, which have large fleshy receptacles whereon a great number of blossoms are crowded; thus a thermometer placed in the centre of five spadixes of the *Arum cordifolium* has been seen to rise to 111°, and one placed in the midst of twelve spadixes has risen to 121°, whilst the temperature of the surrounding air was only 66°. In the *germination* of seeds, also, a great elevation of temperature occurs, which is rendered most

evident by bringing together a number of seeds, as in the process of *malting*, so that the caloric is not dissipated as fast as it is generated; the thermometer, placed in the midst of a mass of seeds in active germination, has been seen to rise to 110°.

763. Thus it is evident that the chemical changes which are involved in the operations of Nutrition are capable of setting-free a large amount of heat; which, although ordinarily dissipated from the vegetating surface too speedily to manifest itself, becomes sensible enough when this rapid loss is checked. If we further examine into the nature of the chemical changes which appear most concerned in this elevation of temperature, we find that they uniformly consist in the combination of the carbon of the plant with the oxygen of the atmosphere; so that a large quantity of carbonic acid is formed and set-free, precisely in the manner of the Respiration of Animals. This process is so slowly performed, in the ordinary growth of Plants, that it is masked (as it were) by the converse change,—the *fixation* of carbon from the carbonic acid of the atmosphere under the influence of light (§ 83). But it takes-place with extraordinary energy during Flowering and Germination; a large quantity of carbon being set-free by union with the oxygen of the air, and the starchy matter of the receptacle or of the seed being converted into sugar. Now it has been ascertained by careful experiments, that the amount of heat generated is in close relation with the amount of carbonic acid evolved; and that if the formation of the latter be prevented, by placing the flower or the seed in nitrogen or hydrogen, no elevation of temperature takes-place; whilst, if the process be stimulated by pure oxygen, so that a larger proportion of carbonic acid is evolved, the elevation of temperature is more rapid and considerable than usual.

764. Upon examining into the conditions under which Caloric is generated in the Animal body, we find them essentially the same. Whenever the temperature of the body is maintained at a regular standard, so as to be independent of variations in the warmth of the surrounding medium, we find a provision for exposing the blood most freely to the influence of oxygen, and for extricating its carbonic acid; thus in Birds and Mammals the blood is distributed through a minute capillary network on the walls of the pulmonary air-cells, the gaseous contents of which are continually renewed; and in Insects the air is carried into every part of the body by the ramifying tracheæ. We find a constant proportion between the amount of Heat evolved and that of Carbonic acid generated: this is peculiarly evident in Insects, whose respiration and calorification vary so remarkably (§ 123); but it is also proved by comparing the amount of carbonic acid evolved by warm-blooded animals, when the external temperature is low, and when more heat must be generated to keep the temperature of their bodies

up to its proper standard, with that evolved by the same animals in a warmer atmosphere, when the generation of animal heat takes-place at a diminished rate (§ 691). The sources of this Carbonic Acid have been already pointed-out (CHAP. IX.): it is partly derived from the metamorphosis of the tissues; but partly, in all save purely carnivorous animals, more directly from the non-azotized portion of the food. But further, it is certain that some of the Hydrogen of the food is burned-off by union with the oxygen of the atmosphere, so as to form part of the water which is exhaled from the lungs. Again, the Sulphur and Phosphorus of the food are converted by oxygenation into sulphuric and phosphoric acids; in which process heat must be generated. And in one way or other, the whole excess of the oxygen absorbed over that which is contained in the carbonic acid exhaled (§ 689), must be applied to purposes in the laboratory of the system, in which caloric will be disengaged. Still, the amount of Carbonic Acid exhaled will always afford a measure of the chemical processes by which Heat is generated in the body; because it is itself the result of the chief of the processes (the union of carbon and oxygen), and because the surplus amount of oxygen which is absorbed and applied to other purposes is closely related to it.

765. Of the force which is generated by these combustive processes, however, only a part manifests itself directly as *Heat;* a considerable portion being applied in the first instance to the production of Motion. And in so far as this portion is expended in *opus mechanicum* (§ 639), that is, in imparting motion either to the body itself or to objects external to it,—it does not become a source of Animal Heat; indeed, as already shown (§ 695), its exercise can only be sustained by a considerable addition to the combustive action which takes place in the body at rest. But the whole of the mechanical force which is in the first instance applied to the *opus vitale,*—being exerted entirely within the body itself,—ultimately manifests itself as Animal Heat; for the *friction* of the blood in its vessels, and of the air in its passages, which this force is primarily employed in overcoming, is in reality nothing else than a conversion of sensible Motion into Heat (molecular motion); and thus the energy which seems to expend itself in the effects immediately produced by the Heart and the Respiratory muscles, ultimately contributes in no small degree to the maintenance of Calorification. Hence in estimating the whole *energy* developed by the Combustive processes, we may leave out of view the *opus vitale,* and consider only the amount of Heat produced and of Mechanical work done.

766. The power of maintaining a high independent temperature is usually much less in *young* warm-blooded animals than in adults. There are considerable variations in this respect, however, amongst different species; for where the young animal is born in

such an advanced condition as to be thenceforth almost independent of parental assistance, it is capable of maintaining its own temperature; but where it is born in such a state as to require to be supplied with food by the parent for some time, it is also more or less dependent upon the warmth imparted to it from the parental body. This is peculiarly the case with the young of the Human species, which is longer dependent upon parental aid than is that of any other animal. In the case of children born very prematurely, the careful sustenance of their heat is one of the points most to be attended-to in rearing them; and even the most vigorous infants, born at the full time, are far from being able to keep-up their proper standard without assistance, if exposed to a cool atmosphere. It has been ascertained that during the first month of infant life, the mortality in winter is nearly double that of summer, being as 139 in January to 78 in July; and this striking difference cannot be attributed to any other cause than the injurious influence of external cold, which the calorifying powers of the infant do not enable it to resist. As age advances, the power of generating heat increases, and the body becomes much more independent of external vicissitudes; so that, in adult life, the winter mortality is to that of summer only as 105 to 91, or less than one-sixth more. In advanced age the calorifying power again diminishes; and this we should anticipate from the general torpor of the nutritive operations in old persons. Between 50 and 65 years of age, the relative winter and summer mortality are nearly as in the first month of infancy; and at 90 years, the average mortality of winter is much more than twice that of summer, being as 158 to 64.

767. It appears that there is a difference is calorifying power, not merely at different ages, but at different seasons; the amount of heat generated in summer not being sufficient, in many animals, to prevent the body from being cooled-down by prolonged exposure to a temperature which is natural to them in winter. To what extent this is the case with Man, it is difficult to say. His constitution is distinguished by its power of adapting itself to circumstances; and he can live under extremes of temperature more wide than those which most other animals can endure (§ 113). Whether in the Torrid zone or in the Arctic regions, he can maintain his healthy condition under favourable circumstances; his natural appetite leading him, in each case, to the use of that kind and amount of food which is best suited to the wants of his system. But the longer he has been habituated to a very warm or a very cold climate, the more difficult he at first finds it to live comfortably in one of an opposite character; as his constitution, having become adapted to one particular set of circumstances, requires *time* to accommodate itself to an opposite one.

768. The means by which the heat of the body is prevented

from rising *above* its normal standard, even in the midst of a very high temperature in the surrounding air, are of the most simple character. The excreting action of the Skin is directly stimulated by the application of warmth to the surface; and the fluid which is poured-forth, being immediately vaporized, converts a large quantity of sensible caloric into latent, and thus keeps-down the temperature of the skin. By this provision, the body may be exposed with impunity to *dry* air of 600° or more, so long as the supply of fluid is maintained. But it cannot long sustain exposure to air saturated with vapour, even though this be not many degrees hotter than the body; because the cooling act of evaporation from the skin cannot then be carried-on.

769. The evolution of LIGHT is a very interesting phenomenon, chiefly witnessed among the lower animals, and usually supposed not to occur in any class above Fishes. It is particularly remarkable among the Radiata and inferior Mollusca. A large proportion of the *Acalephæ*, or Jelly-fish tribe, possess the property of luminousness in a greater or less degree; and it is to small animals of this class, which sometimes multiply to an amazing extent, that the beautiful phenomenon of *phosphorescence of the sea* is usually due. In the midst of the soft diffused light thus occasioned, brilliant stars, ribands, and globes of fire are frequently seen; these appearances being due to the luminosity of the larger species of the same tribe, or to that of other marine animals, especially the floating species of Tunicated Mollusks (§ 557). The diffused luminosity, however, is not unfrequently due to the extraordinary multiplication of a small animal termed *Noctiluca*, resembling in appearance a grain of sago; which, on account of the extreme simplicity of its structure, cannot be referred to any type above the Rhizopod.—Some examples of luminosity which are most remarkable as regards the brilliancy of the light emitted, occur in the class of Insects. Here the emission is confined to one portion of the body, or to two or more isolated spots, instead of being diffused over a larger surface; and it is proportionally increased in intensity.—The phenomenon of Animal Luminousness appears usually attributable to the formation of a peculiar secretion, which, in many instances, continues to shine after removal from the animal, so long as it is exposed to the influence of oxygen: and there is every reason to believe that it undergoes a slow process of combustion, analogous to that which takes place when phosphorus is exposed to the air. There is a special provision in Insects for conveying a large supply of air through the peculiar substance which is deposited beneath the luminous spots; and the power which Glow-worms, Fire-flies, &c., possess, of suddenly extinguishing their light, and as suddenly renewing it, seems to depend upon their control over the air-aperture or spiracle by which air is admitted, the stoppage of the supply of

air causing the immediate cessation of the luminousness, and its re-admission occasioning a renewal of the process on which it depends.—It is probable, however, that in certain cases the luminosity is rather of an electric character. There are several of the smaller *Annelida* or Marine Worms, which are brilliantly luminous when irritated; the luminosity having the character, however, of a succession of scintillations, rather than of a steady glow. It appears, from the experiments of M. Quatrefages, that this peculiar luminosity is the especial attribute of the muscular system; and that it is produced with every act of muscular contraction in these animals.

770. No such luminosity is commonly manifested in any of the higher Vertebrata, or in Man; although luminous emanations from dead animal matter are of no unfrequent occurrence. Several instances have been recorded in which the Urine has been luminous, apparently in consequence of its containing an unusual quantity of unoxidized Phosphorus; and luminosity has even been observed in the Perspiration after violent exertion. There are well-authenticated cases, however, in which the phenomenon has presented itself in the *living* Human subject.* But in most of these cases, the individuals exhibiting the luminosity had suffered from consumption or some other wasting disease, and were near the close of their lives at the time; so that it is probable that a decomposition of the tissues was actually in progress, analogous to that which, when it occurs after death, imparts luminosity to the decaying body. One instance is recorded, in which a large cancerous sore of the breast emitted light enough to enable the hands on a watch-dial to be distinctly seen when it was held within a few inches of the ulcer; here, too, decomposition was obviously going-on, and the phosphorescent matter produced by it was exposed to the oxygenating action of the atmosphere.

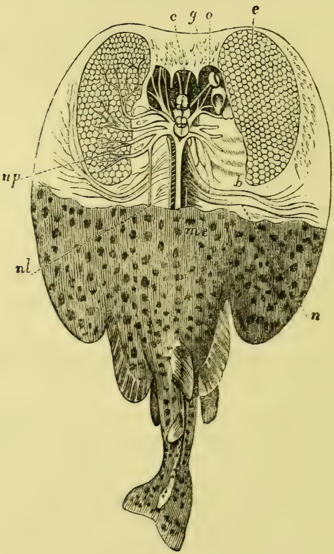
771. Slight manifestations of free ELECTRICITY, or, in other words, disturbances of Electric equilibrium, are very frequent in living animals; and they are readily accounted-for when we bear in mind that every chemical change is attended with some alteration in the electric state of the bodies concerned, and when we consider the number and variety of such changes in the living animal body. When slight, however, they can only be detected by refined means of observation; and it is only when they are considerable, that they attract notice. The most remarkable examples of the evolution of free Electricity in Animals are to be found in certain species of the class of Fishes; the best known of which are the *Torpedo* or Electric Ray, and the *Gymnotus* or Electric Eel.

* See an account of several cases of Evolution of Light in the Living Human Subject, by Sir Henry Marsh, M.D., M.R.I.A., &c.

These possess organs in which Electricity may be generated and accumulated in large quantities, and from which it may be discharged at will. The shock of a large and vigorous Gymnotus is sufficiently powerful to kill small animals, and to paralyze large ones, such as men and horses: that of the Torpedo is less severe, but it is sufficient to benumb the hand that touches it.

772. The electric organs of the Torpedo (which fish, from being found on European shores, has been the most studied) are of flattened shape, and occupy the front and sides of the body; forming two large masses (Fig. 186, *e*), which extend backwards and out-

Fig. 186*.



wards from each side of the head. They are composed of two layers of membrane separated by a considerable space; and this space is

* Electrical Apparatus of Torpedo—*b*, branchiæ; *c*, brain; *e*, electric organ; *g*, cartilage of cranium; *m e*, spinal cord; *n*, nerves to the pectoral fins; *n l*, lateral nerves to the body: *n p*, large nerves (pneumo-gastric) to the electric organ; *o*, eye.

divided by vertical partitions into hexagonal cells like those of a honeycomb, the ends of which are directed towards the two surfaces of the body. These cells, which are filled with a whitish soft pulp, somewhat resembling the substance of the brain, but containing more water, are again subdivided horizontally by membranous partitions; and all these partitions are profusely supplied with blood-vessels and nerves.—The electrical organs of the Gymnotus are essentially the same in structure; but they differ in shape, in accordance with the conformation of the animal.—In these, as in the other Electrical fishes, the electric organs are supplied with nerves of very great size, larger than any others in the same animals, and larger than any nerves in other animals of similar bulk. These nerves, *np*, arise from a peculiar ganglionic enlargement of the Medulla Oblongata, termed the *electric lobe*, and seem chiefly analogous to the Pneumogastrics of other animals.

773. The following conditions appear to be essential to the manifestation of the Electric powers of these animals. Two parts of the body must be touched at the same time; and these two must be in different electrical states. The most energetic discharge is procured from the Torpedo, by touching its back and belly simultaneously; the electricity of the back being positive, and that of the belly negative. When two parts of the same surface, at equal distances from the electric organ, are touched, no effect is produced, as they are equally charged with the same electricity; but if one point be further from it than the other, a discharge occurs, the intensity of which is proportioned to the difference in the distance of the points from the electric organ. However much a Torpedo is irritated, no discharge can take-place through a single point; but the fish makes an effort to bring the border of the other surface into contact with the offending body, through which a shock is then transmitted. This, indeed, is probably the usual way in which the discharge is effected.—The identity of *animal* with *common* Electricity is proved, not merely by the similarity of the effects upon the feelings produced by the shock of both; but also by the fact that a spark may be obtained, and chemical decompositions effected, by the former, precisely as by the latter.

774. The power of the animal over the actions of its Electric organs, is dependent upon their connection with the nervous centres. If all the nerve-trunks supplying the organ on one side be divided, the animal's control over that organ will be destroyed; but the power of the other may remain uninjured. If the nerves be partially divided on either or both sides, the power is retained by those portions of the organs which are still connected with the centres by the trunks that remain. Even slices of the organ entirely separated from the body except by a nervous fibre, may

exhibit electrical properties. Discharges may be produced by irritating the part of the nervous centres from which the trunks proceed, so long as the latter are entire; or by irritating the portions of the divided trunks which remain in connection with the electric organs; or even by irritating portions of the electric organs themselves, when separated from the nervous centres.

775. In all these respects, there is a strong analogy between the action of the nerves on the Electric organs, and their action on the Muscles; and it is another point of analogy between the action of Muscles and that of the Electrical organs, that the former, like the latter, is attended with electric disturbance (§§ 364, 365). The connection of the organs specially appropriated to each of these actions with the Nervous system, the dependence of their continued action upon the integrity of this connection and upon the state of activity of the central organs, the influence of stimulation applied to the nervous centres or trunks, the results of ligature or section of the nerve, and the effects of poisonous agents, are all so remarkably analogous in the two cases, that it seems scarcely possible to doubt that the Nervous force is the agent which is instrumental in producing both sets of phenomena. Still, however, no proof whatever can be derived from this source, of the *identity* of nervous influence with any form of Electricity; since all that can be legitimately inferred from it is, that Nerve-force acting through a particular organic structure developes Electricity, in virtue of the *correlation* formerly explained (§ 395).

776. It was observed by Galvani that there exists in the Frog, during its whole life, a continual current of Electricity, passing from its extremities towards its head; and as no such current has been detected in any other animal, it has been termed the *courant propre*, or peculiar current, of the Frog. It bears this curious analogy to the electric discharges of Fishes; that it is *not* manifested if the connection be made between corresponding points of the opposite sides, but that it shows itself when the communication is made between points higher or lower in the body, whether on the same or on opposite sides. It has now been fully demonstrated, however, by the researches of Matteucci and Du Bois-Reymond, that this 'proper current of the frog' is but a special case of the ordinary muscular current (§ 364), depending upon the peculiar arrangement of the muscular and tendinous elements in this animal. Both currents are alike influenced by agents which affect the vitality of the muscle; and it is curious that poisoning with sulphuretted hydrogen should almost immediately put an end to each, although ordinary narcotic poisons have very little influence.

777. Manifestations of Electricity may be produced, in most animals having a soft fur, by rubbing the surface, especially in

dry weather; this is a fact sufficiently well known in regard to the domestic Cat. Some individuals of the Human race exhibit spontaneous manifestations of electricity, which are occasionally of very remarkable power. There are persons, for instance, who scarcely ever pull-off articles of dress that have been worn next their skin, without sparks and a crackling noise being produced, especially in dry weather. This is partly due, however, to the friction of these materials with the surface and with each other. But the case of a lady was some time since put on record, who was for many months in an electric state so different from that of surrounding bodies, that, whenever she was but slightly insulated by a carpet or other feebly-conducting medium, sparks passed between her person and any object which she approached. When she was most favourably circumstanced, four sparks per minute would pass between her finger and the brass ball of a stove, at a distance of $1\frac{1}{2}$ inch. Various experiments were tried with the view of ascertaining if the Electricity was produced by the friction of articles of dress; but no change in these seemed to modify its intensity. From the pain which accompanied the passage of the sparks, this condition was a source of much discomfort to the subject of it.

CHAPTER XII.

OF GENERATION AND DEVELOPMENT.

1. *General View of the Nature of the Process.*

778. There is no one of the functions of living beings, that distinguishes them in a more striking and evident manner from the inert bodies which surround them, than the process of Generation. By this function, each *race* of Plants and Animals is perpetuated; whilst the *individuals* composing it successively disappear from the surface of the earth, by that death and decay which are the common lot of all. There are certain tribes in which the death of the parent is necessary for the liberation of the germs from which a new race is to spring-up. This is the case, for example, in some of the simplest Cellular Plants; in which every cell lives for itself alone, and performs its whole series of vital operations independently of the rest. But as, in more complex organisms, we find certain cells set-apart for Absorption, others for Secretion, &c., so do we find a particular group of cells set-apart for Reproduction; and these go through a series of changes peculiar to themselves, without interfering with the general life of the

structure.—It is in the Vegetable kingdom that the essential character of the Generative process can be best studied; and we shall in the first instance, therefore, inquire into the nature and import of the principal phenomena which it presents.

779. If we take as our starting-point the simple cell in which the *individuality* of the lowest Algæ seems to reside, we find that such a cell, under the influence of light and warmth, and supplied with aliment, multiplies itself to an extent that almost seems unlimited; and this by a process of duplication (Fig. 187) exactly analogous to that which has been already described (§ 256) as taking-place in Cartilage. Now although the effect of

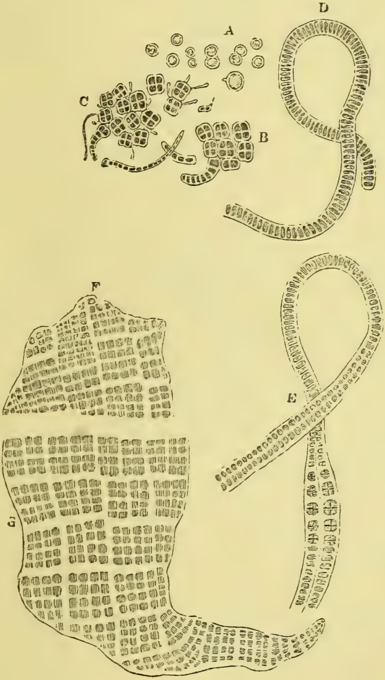
Fig. 187.*

this operation is to produce a great number of new cells, yet it cannot be truly considered as an act of Generation; for it is obviously analogous to that multiplication of the component cells, which takes-place as a part of every process of *growth* in the most complex organisms; the only difference being, that the new cells are here in a great degree independent one of another, so as to be able to maintain their existence when isolated; whilst among the higher tribes, there is so close a relation of mutual dependence between the component cells, that they cannot continue to live if separated one from another. And we shall hereafter see that the early development of the embryonic mass, even in the highest Animals, presents phenomena in all respects com-

* Various stages of development of *Hæmatococcus binalis*;—*a*, *a*, simple rounded cells; *b*, elongated cells, the endochrome preparing to divide; *c*, *c*, cells in which the division has taken-place; *d*, cluster of four cells formed by the repetition of the same process.

parable to this multiplication of the simplest Cellular Plants by successive subdivision (§ 805); all the descendents of the original cell, however, here remaining in mutual apposition, and concurring to make-up what is commonly designated as a single

Fig. 188.*



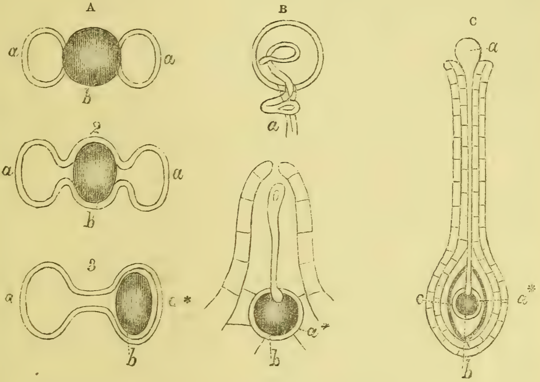
* Successive stages of development of simple Algæ:—A, individual cells of *Protococcus viridis;* B, C, clusters formed by their multiplication; D, filament of *Schizogonium murale;* E, a similar filament, subdividing laterally, which constitutes the early form of the *Ulvaceæ;* F, G, portions of the expanded thallus of *Ulva furfuracea*, formed by the continuance of the same process of transverse subdivision.

individual; whilst in the simplest Plants, these cells, as their number is successively augmented by fission, are more and more widely separated from each other, and may disperse themselves over an extensive surface.—If, however, they should remain in mutual connection, they may form clusters (Fig. 188, B, C), filaments (D, E), or fronds (expanded leafy surfaces, F), according to the direction in which the subdivision takes place; and this without the slightest departure from the original cellular type, which is preserved throughout the structure, every part being exactly similar to every other.—In these composite organisms, we usually find a provision, not merely for the extension of the original structure, but for the multiplication of individuals; which, being still referable to the general type of cell-subdivision, must be considered as a process of *extension* rather than of *generation*. This consists in the emission, from certain of the cells, of broods of young cells formed in their interior; and these, in the lower aquatic plants, are very commonly furnished with cilia, by the agency of which they are dispersed through the water, beginning to develope themselves into the likeness of the organisms from which they sprang, as soon as their movement has ceased. These 'zoospores,' as they are termed, must be regarded as the representatives of the *gemmæ* or buds of higher Plants. The latter are usually developed in continuity with the stock from which they originate; but there are many instances in which they are spontaneously detached; and there are few cases in which they will not continue their existence under favourable circumstances, when artificially separated from it, as is practised in the operations of grafting, budding, &c.

780. The true Generative process, on the other hand, seems to consist, throughout the Vegetable kingdom, in the *reunion* of the contents of two cells which have been separated in the process of growth and multiplication, and in the production of a *germ* as the result of this reunion, which is usually very different in its characters and properties from either of the cells whose contents have contributed to form it. This process has been observed to take place in the Vegetable kingdom under three different forms, which seem to be characteristic of the lowest Cryptogamia, of the higher Cryptogamia, and of the Phanerogamia, respectively.—The *first* of these presents itself in those simple Cellular Plants, in which, whether the cells remain in connection or not, their endowments are all of the same nature. At a certain time of the year (it would seem) in each species, the cells approach one another in pairs, and their endochromes (or coloured contents) are intermingled (Fig. 189, A), either by the rupture of both cells (1), or by the formation of a direct communication from the interior of one to that of the other, in which last case the union of the two endochromes may take-place either in the connecting channel (2)

or in one of the pair of cells (3). Of this process, which is known as *conjugation*, the result is the formation of a peculiar cell, from which a 'new generation' is developed by the subsequent process

Fig. 189.*



of fission and multiplication, and which may be appropriately termed the 'primordial cell.' There is here no definite distinction of the sexes, the conjugating cells being apparently alike in their endowments: such a distinction is shadowed-forth, however, where the sporangium is developed within one of them.—The second form of the true generative process is seen even in the higher Algæ; and although the extent of its prevalence has not yet been certainly determined, it is probably common to the Lichens, Fungi, Liverworts, Mosses, and Ferns. In conformity with the separation or specialization of organs which is characteristic of these Plants, we find that the Generative power is now

* Diagram representing the three principal forms of the Generative process in Plants:—A, conjugation of inferior Cryptogamia; formation of the primordial cell, *b*, by admixture of the discharged endochromes of the parent-cells, *a*, *a*; 2, production of the primordial cell, *b*, within a dilatation formed by the union of the two parent-cells; 3, production of the primordial cell, *b*, by the passage of the endochrome of cell *a* into that of cell *a**, marking-out a sexual difference.—B, fertilization of germ in higher Cryptogamia; *a*, sperm-cell discharging its spiral filament; *a**, germ-cell, against which one of these filaments is impinging; *b*, primordial cell produced by their contact.—C, fertilization of germ in Phanerogamia; *a*, germ-cell, or pollen-grain, sending its prolonged tube down the style, until it reaches *a**, the germ-cell, inclosed in the ovule, the section of whose coats is shown at *c*; from the contact of the two is produced the germ or primordial cell, *b*.

limited to certain small parts of them, and that these produce two orders of cells, very distinct in their endowments, which may be called respectively 'sperm-cells' and 'germ-cells.' It is from the latter that the new plant originates; but this it can only do when the fertilizing influence of the former has been conveyed to it; and the provision for this purpose is very remarkable. The 'sperm-cells,' developed within bodies termed *antheridia*, form in their interior, as their characteristic products, minute spirally-coiled filaments, usually furnished with cilia at one extremity, and bearing a very close resemblance to the spermatozoa of animals (§ 787). These 'antherozoids,' when liberated from the cells within which they were formed, possess a very active power of movement, in virtue of which they make their way to the 'germ-cells;' and when they have impinged against these, there is reason to believe that they dissolve-away, and that the product of their diffluence is absorbed into the germ-cells and mingles with the contents of the latter, the formation of a 'primordial-cell' being the result of this intermixture (Fig. 189, B). Here, then, we have the distinction of sexes well marked; but both 'sperm-cells' and 'germ-cells' are usually developed in the same organism, and are alike the product of a single original germ. Throughout the Cryptogamic series, the fertilized germ appears to be thrown at once upon the world, and is dependent for its supply of food upon its own absorbing and assimilating powers; these enable it to multiply itself by fission, sometimes to a vast extent; and thus an elaborate and complex organism (such as a Tree-Fern) may be produced.—In the *third* form of the generative process, which is peculiar to Phanerogamia (or Flowering Plants), there is the same distinction between 'sperm-cells' and 'germ-cells;' but the mode in which the action of the former upon the latter is brought-about, is very different. The 'sperm-cell,' which is here known as the 'pollen-grain,' and is developed in the anthers of the flower, does not evolve self-moving filaments, but, when it falls upon the apex of the style, puts-forth long tubes, which insinuate themselves down between its loosely-connected tissue, until they reach the ovary at its base. Here they meet with the ovules, which are in reality 'germ-cells' imbedded in a mass of nutriment stored-up by the parent; and the pollen-tube, entering the micropyle or foramen of the ovule, penetrates into such close approximation to the germ-cell contained within it, that its contents find a ready passage by endosmose into the latter (Fig. 189, c). Here again, therefore, we have the same essential phenomenon,—the intermixture of the contents of the sperm-cell and of the germ-cell, as the condition for the development of the true germ. But this germ, still making its first appearance as a single cell within the ovule, is supplied with nutriment by its parent; and this not merely whilst the ovule remains in connection with the organism

which evolved it, but for some time subsequently; the store laid up around it in the seed, being the material at the expense of which its early development takes place. It is not, in fact, until its true leaves have been evolved and its root-fibres have penetrated the soil, as takes-place in the act of germination, that it becomes capable of absorbing and assimilating nutriment for itself. So soon, however, as germination has been completed, the young plant becomes independent of further assistance; and all its subsequent growth is provided-for by its own powers. In process of time its own generative apparatus is evolved; and here, too, we find that the two sets of sexual organs are usually developed in the same organism, it being only a small proportion of Phanerogamia that are *diœcious*, *i. e.*, that have the male or staminiferous flowers, and the female or pistilline, restricted to different individuals.

781. The history of embryonic Development in Flowering Plants, presents some interesting points of correspondence with that of the higher Animals.—The germ that is developed within the germ-cell (here designated the 'embryonic vesicle' of the ovule) as the product of the admixture of its contents with those of the sperm-cell (or pollen-grain), is itself a single cell; and the early history of its development closely resembles that which may be observed in all the inferior Plants. In the first place it subdivides into two, each of these into two others, and so on; its first *nisus* or tendency being to the production, not of the parts which are to be evolved into the stem, roots, leaves, &c., of the perfect plant, but of a leaf-like expansion, which may be likened to the frond of the Cryptogamia, and of which the function is only temporary. It is by this organ, the single or double *cotyledon*, that the nourishment provided in the ovule is absorbed and prepared for the development of the young Plant; the permanent fabric of which, even at the time of the maturity of the seed, forms but a small proportion of the entire embryonic structure. In the act of germination, however, the permanent portions are developed at the expense of the temporary, the plumula and radicle absorbing the nourishment which has been elaborated by the cotyledons; and having fulfilled its transient purpose, and completed its term of life, the first leaf-like expansion withers and dies. The tissues of the young Plant are at first of the simplest possible character; but as the organs characteristic of its adult condition are one after another put-forth (always originating in peculiar groups of cells), so do we find that the spiral vessels, woody fibre, &c., characteristic of the higher organisms, gradually make their appearance.—Thus we see that even the highest Plants have to pass through grades of development closely conformable to those which are permanently shown in the lower; and that the parts which are first formed are destined for only a temporary purpose, that of

preparing nourishment for the evolution of more permanent structures. We shall find, in tracing the history of the development of the higher Animals, that exactly the same general fact may be observed in even a more striking manner; the number of different stages being greater, and a yet larger proportion of the parts first formed having a merely temporary purpose, and being destined to an early decay so soon as the more permanent parts of the fabric shall have been evolved.

782. Among many of the lower Animals, a multiplication of individuals takes-place by a process that closely resembles the *budding* of Plants; this also must be regarded, not as a proper act of Generation, but as a modification of the ordinary Nutritive process. The same may be said of the powers of reparation which every Animal body possesses in a greater or less degree, but which are by far the most remarkable among the lower tribes; for when an entire member is renewed (as in the Star-fish), or even the whole body is regenerated from a small fragment (which is the case in many Polypes), it is by a process exactly analogous to that which is concerned in the reparation of the simplest wound in our own bodies, and which is but a modification of the process that is constantly renewing, more or less rapidly, every portion of their fabric. Although the buds thus produced and separated are usually developed into the likeness of the parent stock, yet this is sometimes not the case, the stock possessing one form, and the bud another which may be quite different; as when certain fixed composite Zoophytes bud-off free-moving solitary Medusæ, these last depositing ova from which the Zoophytic type is regenerated. When, however, this phenomenon, to which the name of 'alternation of generations' has been given (erroneously in the Author's opinion), is carefully examined, it is found that the bud thus detached is really the generative apparatus of the parent stock, furnished (it may be) with nutrient and locomotive organs of its own; so that neither can be regarded as a complete organism without the other. Thus the Medusa contains the proper generative apparatus of the Zoophyte, which developes no other; and the 'aggregate' Salpæ that are budded forth from a kind of stalk in the interior of the 'solitary' form, must be regarded as altogether constituting its true generative apparatus, since it never produces any other. In all instances, it will be found that whatever may be the variations which present themselves in the entire history of any species, the immediate product of the true Generative act is uniformly the same.

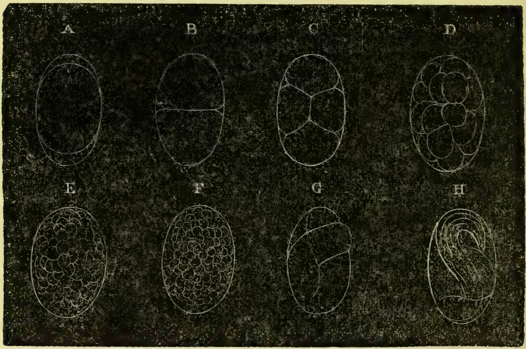
783. This act, in Animals as in Plants, requires the concurrent action of two sets of organs, evolving 'sperm-cells' and 'germ-cells' respectively; and it is curious that these should present the closest approach to those of the higher Cryptogamia, rather than to those of Plants above or below them in the scale. The two

sets of organs may be united in the same individual, as they are in most Plants; and the ova may be fertilized from the seminal cells of the same being;—as happens in many Zoophytes, and in some of the lowest tribes of Mollusks. Or, the two sets of organs being present in each individual, it may not be capable of self-impregnation; but, in the congress of two individuals, each impregnates, and is impregnated by, the other;—as may be observed in the Snail and many of the higher Mollusks. Or the sexes may be altogether distinct; one individual possessing only the *male* or spermatic organs, and the other the *female* or germ-nourishing apparatus;—this is observed in the higher classes of the Radiated, Molluscous, and Articulated sub-kingdoms; and it is the case in all Vertebrata.

784. The earliest part of the history of Embryonic Development is nearly the same in all Animals; for it consists in the multiplication of the single cell of which the original germ is composed, until a cluster is formed, all the cells of which appear to be in every respect similar one to another. Each of these cells either takes into itself, or draws around it, a portion of the *vitellus* or yolk, which is the nutrient substance of the ovum; and thus either the whole of this vitellus, or a portion of it, is subdivided into a number of minute spherules, altogether constituting what is known as the 'mulberry mass' (Fig. 190, E). The former seems to be the case when the grade of development of the organism which is to be formed at the expense of the yolk is very low; whilst the latter plan is followed when the yolk is destined to afford a prolonged sustenance to the embryo, which attains a high degree of development whilst supported upon it alone. Thus, among the Invertebrata generally, we find that the embryo comes-forth from the egg in a very simple condition, a large part of its structure having undergone but little change from the state of the 'mulberry mass;' and in these the whole yolk undergoes subdivision. The same is the case, too, in the Batrachian Reptiles, which issue from the egg in a form very different from that into which they are to be subsequently developed; and it is the case even with Mammals, but for a very different reason, their embryonic structure first formed at the expense of the yolk being destined to acquire additional material for its full development from a source altogether different. In the highest Mollusks, however, as also in Fishes, ordinary Reptiles, and Birds, the portion of the yolk which undergoes subdivision is comparatively small; and the great mass of the vitellus is destined to be subsequently absorbed into the substance of the germ, by a process analogous to that by which the food of the adult is imbibed. Hence the portion of their yolk which undergoes subdivision, and helps to constitute the 'mulberry mass,' may be distinguished as the 'germ-yolk,' the remainder being termed the 'food-yolk.'

785. When the whole of the yolk is taken into the 'mulberry mass,' the formation of the embryo is usually the result of the progressive metamorphosis of its parts; the cells of its surface being converted into the integument, and those of its inner part into the internal organs. This is the case, for example, in the Intestinal Worm, some of the stages in whose development are shown in Fig. 190, F, G, H. The embryonic condition of many

Fig. 190.*



of the organs is frequently retained at the time when the young animal comes-forth from the egg; those parts only being completed, which are necessary to enable it to obtain its nutriment. Other organs are subsequently evolved at the expense of the food introduced by these; and thus a complete change or *metamorphosis* may take-place, in regard alike to external form and to internal structure, between the larval and the adult states. Of this phenomenon, we have characteristic examples in the groups of Insects and Batrachia; and although it was formerly considered exceptional, it is now known to be the ordinary occurrence among the lower tribes of animals, comparatively few of which come forth from the egg under their adult forms. The change is sometimes obviously gradual, as in the progressive advance of the Tadpole into the condition of the Frog; but it is sometimes

* Successive stages of segmentation in the vitellus of the Ovum of *Ascaris acuminata*:—A, ovum recently impregnated, the yolk-bag slightly separated from the enveloping membrane; B, first fission into two halves; C, second fission, forming four segments; D, yolk, now divided into numerous segments; E, formation of 'mulberry mass' by further segmentation; F, the mass of cells now beginning to show the form of the future worm; G, further progress of its evolution; H, the worm, formed by the conversion of the yolk-cells, now nearly mature.

apparently sudden, as when the Chrysalis-skin is thrown-off, and the perfect Insect comes-forth. In the latter case, however, the change is really just as gradual as in the former; since the organs characteristic of the perfect Insect are undergoing development during the whole of the Chrysalis period, to be displayed and brought into use at its termination. Thus the whole life of the Insect, up to its last change, may be regarded as one of prolonged embryonic development; and the same may be said of that of the Frog, up to the time when its permanent organs are fully evolved.—No such ostensible metamorphosis takes-place, however, in the animals which are provided with a 'food-yolk;' for this supplies that material for the continued development of the embryo *within* the egg, which is elsewhere to be obtained *out* of it; and thus the embryo is supported until it has nearly attained its adult *condition*, although far from having acquired its adult *size*.* Now in all these cases, it is very interesting to remark that the first *nisus* is towards an extension of the embryonic mass as a membranous expansion (evidently analogous to the cotyledon of the Flowering Plants, § 781) over the 'food-yolk;' in this 'germinal membrane,' which forms a sort of temporary stomach, blood-vessels are developed, which absorb the prepared nutriment and convey it to the permanent portion of the embryonic structure; and when its function is completed, the store of aliment being exhausted, and the proper nutrient apparatus of the embryo being ready for action, we lose sight of it altogether. We shall find that a similar germinal membrane is formed in the Human ovum, although there is no 'food-yolk;' its formation being apparently requisite for ulterior purposes, and only a portion of the mulberry mass being employed in giving origin to the permanent part of the embryonic structure.

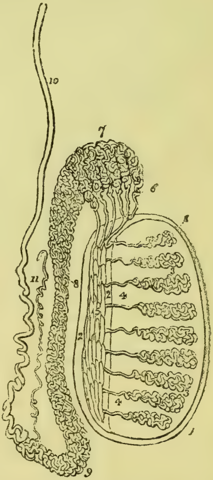
2. *Action of the Male.*

786. The share in the Reproductive function which belongs to the Male Sex, essentially consists in the formation and liberation of the fertilizing bodies termed *Spermatozoa*. These, like the antherozoids of Plants (§ 780), are prepared within peculiar cells, distinguished as 'sperm cells;' which are either scattered through the soft parenchyma of the body, as happens among some of the lowest animals; or are confined to certain parts of it, as in those a little more elevated in the scale; or are formed within follicles or tubes, clustered-together into an organ of a glandular character,

* A very curious provision has been shown by the Author to exist among the higher Gasteropod Mollusks; by which the embryo that is formed from the 'germ yolk,' and comes forth in a very premature condition, is enabled to attain a more advanced development by *swallowing* a large quantity of 'food-yolk' that has been stored-up with it.—See his *Manual of the Microscope*, 3rd Edition, § 384.

known as the *Testis.* Such an organ is found in all Insects and Mollusks, as well as in Vertebrated Animals. In the first of these clases, it is formed on the general plan of their proper glands (§ 720); being usually composed of tubes more or less elongated, and sometimes terminating in enlarged follicles. In the Mollusks, on the other hand, it is almost invariably composed of clusters of follicles. In either case, the seminal cells are developed within the tubes or follicles, as are the ordinary secreting cells of the Liver or Kidney within the tubes or follicles of those glands; and their contents are discharged by an excretory duct, which terminates in an organ that conveys them out of the body, either emitting them into the surrounding water (as happens with many Mollusks), or depositing them within the body of the female. It is curious that in some of the lowest Fishes, we should return to one of the simplest conditions of this organ,—a mass of vesicles, without any excretory duct. In these cases, the secretion formed within the vesicles escapes by their rupture into the abdominal cavity; whence it passes out by openings that lead directly to the exterior.—The *Testis* in Man (Fig. 191) is formed, in every essential particular, upon the plan of the ordinary Glands. It consists of several distinct lobules, separated by processes of the fibrous envelope, or tunica albuginea, which pass down between them; and each lobule consists of a mass of convoluted *tubuli seminiferi,* through which blood-vessels are minutely distributed. The diameter of these tubuli is tolerably uniform; being, when they are not over-distended, from 1-195th to 1-170th of an inch. They form frequent anastomoses with each other; and on this account it is difficult to trace-out their free or cæcal extremities. The tubuli of each testis discharge their contents into an efferent

Fig. 191.*

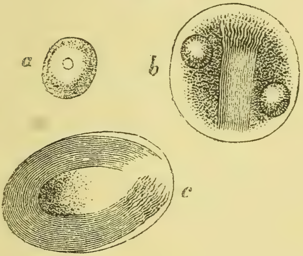


* Plan of the structure of the Testis:—1, 1, the tunica albuginea; 2, 2, the mediastinum testis; 3, 3, the lobuli testis; 4, 4, the vasa recta; 5, the rete testis; 6, the vasa efferentia, of which six only are represented in this diagram; 7, the coni vasculosi, constituting the globus major of the epididymis; 8, the body of the epididymis; 9, the globus minor of the epididymis; 10, the vas deferens; 11, the vasculum aberrans.

duct, the Vas deferens; and by this the product is conveyed into the Vesicula seminalis on each side, which, like the gall-bladder and urinary bladder, serves to store-up the secretion until the proper time arrives for discharging it. The product of the action of the Testis consists of a fluid through which the Spermatozoa are diffused; these last bodies being usually set-free by the rupture of the seminal cells, before they leave the tubuli of the testis. It is difficult to determine the precise characters of the fluid portion of the secretion; as this is mingled with other secretions (such as that of the Prostate gland, and of the mucous lining of the Vesiculæ seminales and spermatic ducts,) before it is emitted. And an exact analysis is not of much consequence; since there can be no doubt that the peculiar powers of the fluid depend upon the Spermatozoa. It may be stated, however, that the Spermatic fluid has an alkaline reaction, and that it contains albumen, together with a peculiar animal principle termed Spermatine; and that it also includes saline matter, consisting chiefly of the muriates and phosphates, especially the latter, which form crystals when the fluid has stood for some little time.

787. The sperm-cells of Man (Fig. 192, *a*) are developed

Fig. 192.*



within the tubuli of the Testicle; where they appear to hold exactly the same relation to the membranous walls of those tubuli, as do the ordinary secreting cells to the tubes and follicles of the proper Glands; being, in fact, the representatives of their epithelial cells. Each of these developes in its interior a variable number of secondary cells, or 'vesicles of evolution;' and within every one of these is produced a single thread-like body, dilated

* Formation of Spermatozoa within seminal cells; *a*, the original nucleated cell; *b*, the same enlarged, with the formation of the Spermatozoa in progress; *c*, the Spermatozoa nearly complete, but still enclosed within the cell.

at one extremity, and possessed of a remarkable self-moving power, which is termed a Spermatozoon. Sometimes the vesicles of evolution remain enclosed within the parent-cell, until their spermatozoa have been completely developed, and have been set free by their rupture (*b*); and thus, when they have all performed their office, the parent-cell contains nothing but a bundle of spermatozoa (*c*), whose dispersion takes place as soon as its cell wall gives way.—From the very peculiar motion they possess, the Spermatozoa were long regarded as distinct and independent Animalcules; it is now known, however, that they have no more claim to a distinct animal character, than have the ciliated epithelia of mucous membrane, which will likewise continue in movement when separated from the body. We have seen that similar bodies are formed by all the higher Cryptogamic Plants (such as Liverworts, Mosses, and Ferns); and that their office, as in Animals, is to fertilize the contents of the 'germ-cells,' with which their self-moving power brings them into contact (§ 780). It is a curious fact that the seminal cells in which the Spermatozoa are formed, are ejected from the gland in certain Crustacea, not only before they have burst and set-free their Spermatozoa, but even long before the development of the Spermatozoa in their interior is completed;—thus affording a complete demonstration of their independent vitality.—The Human Spermatozoon consists of a little oval flattened 'body,' from the 1-600th to the 1-800th of a line in length; from which proceeds a filiform 'tail,' gradually tapering to a very fine point, of 1-50th or at most 1-40th of a line in length. The whole is perfectly transparent; and nothing that can be called structure can be satisfactorily distinguished within it. The movements are principally excited by the undulations of the tail, which give a propulsive action to the body. They may continue for many hours after the emission of the fluid; and they are not checked by its admixture with other secretions, such as the urine and the prostatic fluid. When the seminal fluid remains in contact with a living surface (as when deposited in the generative organs of the female), the Spermatozoa may retain their vitality for some days; and thus fecundation may be subsequently effected in an ovum which was not mature at the time of sexual intercourse.

788. The power of procreation does not exist in the Human Male (except in rare cases) until the age of from 14 to 16 years: at which epoch the sexual organs undergo a much-increased development, and the instinctive desire which leads to the use of them is awakened in the mind. From that time the procreative power remains to an advanced age in the healthy state of the system, unless it be exhausted by excessive use, or by too energetic a direction of the mental or corporeal powers to some other object. The formation of Seminal fluid being, like the proper

acts of Secretion, very much influenced by conditions of the Nervous System, is increased by the continual direction of the mind towards objects which arouse the sexual propensity; and thus, if sexual intercourse be very frequent, a much larger quantity of the fluid will be produced than if it is more rarely emitted, although the amount discharged on each occasion will be less. The formation of this product is evidently a great tax upon the corporeal powers; and it is a well-known fact that the highest degree of bodily and mental vigour is inconsistent with more than a very moderate indulgence in sexual intercourse, whilst nothing is more certain to reduce the powers both of body and mind than excess in this respect.

789. It may be stated as a general law, prevailing equally in the Vegetable and Animal kingdoms,—that the development of the individual, and the reproduction of the species, stand in an inverse ratio to each other. We have seen that in many organized beings the death of the parent is necessary to the production of a new generation; and even in numerous species of Insects, it follows very speedily upon the sexual intercourse. It is a curious fact, that Insects which usually die, the male almost immediately after the act of copulation, and the female very soon after the deposition of the eggs, may be kept alive for many weeks or even months, by simply preventing the copulation. And there can be no doubt that, in the Human race, early death is by no means an unfrequent result of the excessive or premature employment of the genital organs; and where this does not produce an immediately-fatal result, it lays the foundation of future debility, that contributes to produce any forms of disease to which there may be a constitutional predisposition, especially those of a scrofulous nature.

790. The emission of the Spermatic fluid is an act of a purely *reflex* nature; the Will having no power either to effect or to restrain it. The stimulus is given by the friction of the surface of the Glans Penis against the rugous walls of the Vagina, the sensibility of the organ being at the same time much increased by the determination of blood to it (§ 402). The impression is at last sufficiently strong to produce, through the medium of the lower part of the Spinal cord (which is the ganglionic centre of the circle of afferent and efferent nerves connected with this organ), a reflex contraction of the muscular walls of the Vasa Deferentia. These discharge their contents into the urethra; and a like action causes the fluids of the Vesiculæ Seminales and of the Prostate Gland (which seem to serve for the dilution of the semen) to be poured into that canal; from which they are expelled with some degree of force, and with a kind of spasmodic action, by its own Compressor muscles. Although the sensations concerned in this act are ordinarily most acutely pleasurable, yet

there appears to be sufficient evidence that they are by no means essential to its performance; and that the impression conveyed to the Spinal cord may excite the contraction of the Ejaculator muscles, like other reflex operations, without producing sensation (§ 391).

3. *Action of the Female.*

791. The share of the Female in the Generative act is greater than that of the Male; for she not only furnishes, in the 'germ cell,' a product which is as essential as that supplied by the 'sperm-cell' for the first formation of the germ; but she also supplies it with the materials which it requires for its development, up to the stage at which it can support its own life. The mode in which this is accomplished is essentially the same with that in which the process is effected in Plants. In certain parts of the female structure are developed peculiar bodies termed *ova;* which contain, not merely the germ-cells, but in addition a store of nutriment adapted to supply the wants of the germ. The fertilizing influence finds its way into these; and the germs thus produced begin to grow at the expense of the material with which they are surrounded. This, as already pointed-out, may enable the embryo to develope itself without any further assistancce (save a warm temperature) into the form it is permanently to assume; as in the case of Birds and Reptiles, which do not come forth from the investments of the egg, until they have attained the form characteristic of the group to which they belong. Or it may only serve for the early part of the process; and one of two methods may then be employed to complete it. Either a new connection is formed between the parent and the embryo, by which the former continues to supply the latter with nutriment more directly from its blood, as in the case with Mammals: or the embryo issues from the egg in a condition very unlike that which it is permanently to attain, but in a form which enables it to acquire its own nourishment, and to pass through the latter stages of its evolution quite independently of any assistance from its parent, as is the case with Frogs and a large proportion of the Invertebrata (§ 785).

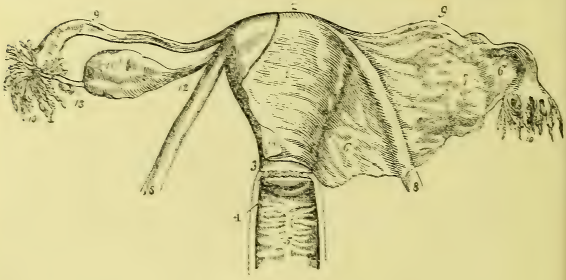
792. The Ova, like the seminal cells, are scattered through the soft parenchyma of the body in animals of the lowest class; but they are more commonly developed in certain distinct portions of the fabric; being sometimes formed in the midst of solid masses of ordinary connective tissue; whilst in other instances they are developed, like the spermatic cells, in the interior of tubes and vesicles resembling those of glands, and furnished with an excretory duct. The latter condition obtains in the greater proportion of the higher Invertebrated animals and in some Fishes; but in

the Vertebrated classes we return to the type which characterises the egg-producing organs in many Zoophytes, — namely, the development of the egg in the midst of a mass of solid parenchyma, from which it gradually makes its way to escape into the visceral cavity. The Ovarium of the Mammal, Bird, or Reptile, as well as that of most Fishes, differs entirely, therefore, from that of the higher Invertebrata; for the latter have all the essential characters of true Glands; whilst the former are nothing else than masses of parenchyma, copiously supplied with blood-vessels, and having dispersed through their substance certain peculiar cells, termed *Ovisacs*, within which the ova are developed. In order that the latter may be set-free, not only must the ovisac itself burst (like parent-cells in general), but the peculiar tissue and the envelopes of the ovarium must likewise give-way. When the ova thus escape into the abdominal cavity, they may lie there for some time, at last to be discharged through simple openings in its walls, as happens in those Fishes which have this form of ovarium; or they may be at once received into the trumpet-shaped expansions of tubes that shall convey them to these orifices. These tubes are termed *oviducts*, in common with the excretory ducts of the glandular ovaria of Invertebrated animals; for their function is the same,—that of conveying the ova to the outlet by which they are extruded from the body. They are represented in Mammalia by the Fallopian tubes, which are true oviducts, although they terminate in the uterus instead of proceeding directly to the outlet. And it is by the fimbriated extremities of the Fallopian tubes (Fig. 193, 10, 10), which apply themselves closely to the surface of the ovaries at the time of the discharge of the ova, that these are received and conveyed to the uterus, instead of being allowed (as in some of the lower animals) to fall into the abdominal cavity.

793. There are many cases among the lower classes, in which the ovum is retained within the oviducts, so that the young comes into the world alive; and there are a few in which, during this delay, it receives a direct supply of additional nourishment from the fluids of its parent. It is in the Mammalia, however, that we find the most remarkable and complete provision for this purpose. Still, the lowest division of this group approximates closely, in the type of its generative apparatus, to the Oviparous Vertebrata; for the oviducts of the *Monotremata* remain distinct from each other, and terminate separately in the uro-genital canal, each of them having first undergone dilatation into a uterine cavity, so that those animals have two completely-distinct uteri. In the *Marsupialia* there is a closer approximation of the two lateral sets of organs on the median line; for the oviducts converge towards one another, and meet on the median line, but without coalescing; so that these animals have a true 'double uterus,' opening by two

orifices into the vaginal canal, a condition which is sometimes met-with as a malformation in the Human female. The vaginal canal, however, is also double; which is less frequently observed

Fig. 193.*



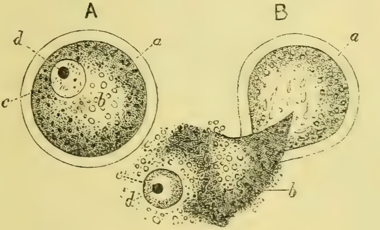
in the Human species. The two preceding orders constitute the sub-class of *Implacental* Mammals; the development of their ova within the uteri being cut short at a period anterior to the formation of the placenta (§ 818).—As we ascend through the series of *Placental* Mammals, we find the lateral coalescence of the uterine dilatations of the Fallopian tubes becoming more and more complete. It first shows itself in the vagina, which is everywhere single, although a trace of separation into two lateral halves is seen in the Mare, Ass, Cow, Pig, and Sloth, in which animals it is traversed, in the virgin state, by a narrow vertical partition. In many of the Rodentia, the uterus still remains completely divided into two lateral halves, opening into the vagina by separate orifices; whilst in others, these coalesce at their lower portion, forming a rudiment of the true 'body' of the uterus of the Human female. This part increases in the more elevated Herbi-

* The Uterus with its Appendages viewed on their anterior aspect:—1, the body of the uterus; 2, its fundus; 3, its cervix; 4, the os uteri; 5, the vagina; the number is placed on the posterior raphé or columna, from which the transverse rugæ are seen passing off at each side; 6, 6, the broad ligament of the uterus; 7, a convexity of the broad ligament formed by the ovary; 8, 8, the round ligaments of the uterus; 9, 9, the Fallopian tubes; 10, 10, the fimbriated extremities of the Fallopian tubes; on the left side the mouth of the tube is turned forwards in order to show its ostium abdominale; 11, the ovary; 12, the utero-ovarian ligament; 13, the Fallopio-ovarian ligament, upon which some small fimbriæ are continued for a short distance; 14, the peritoneum of the anterior surface of the uterus; this membrane is removed on the left side, but on the right is continuous with the anterior layer of the broad ligament.

vora and Carnivora at the expense of the lateral ununited portions, which are now termed the 'cornua;' but even in the lower Quadrumana the uterus is somewhat cleft at its summit, and the 'angles' into which the oviducts enter, form a considerable part of the whole organ. As we ascend through the Quadrumanous series towards Man, we find the 'body' of the uterus increasing, and the 'angles' diminishing in proportion, until the original division is completely lost-sight-of, except in the slight dilatation of the cavity at the points at which the Fallopian tubes enter it.

794. Having thus briefly noticed the most important characters of the organs provided for the original production and for the subsequent reception of the ova, we have now to inquire into the history of their development.—The essential structure of the *ovule*, or unfertilized egg, appears to be the same in all animals. It consists externally of a membranous sac, termed, from the nature of its contents, the *vitelline membrane* or 'yolk-bag.' The *vitellus* or 'yolk' (Fig. 194) consists chiefly of albumen and oil-globules; and, floating in this fluid is seen a cell of peculiar aspect (*c*), termed the *germinal vesicle*, upon the wall of which is a very distinct nucleus (*d*) termed the *germinal spot*. An important distinction exists in the vitellus of the Bird and of many

Fig. 194.*



other oviparous animals, between the 'germ-yolk' and the 'food-yolk;' for the process of segmentation (§ 785) which lays the foundation of the embryonic structure is restricted to the former, and the appropriation of the latter is subsequently effected by a provision of an altogether different kind (§ 815).—The layer of albumen surrounding the yolk, and termed the *white* of the Bird's egg, together with the membrane which envelopes this and forms the basis of the shell, are not added until after the ovum has left

* Human Ovum, A, entire, B, ruptured by pressure :—*a*, vitelline membrane, or zona pellucida; *b*, vitellus; *c*, germinal vesicle; *d*, germinal spot.

the ovarium, being formed by a secretion from the wall of the oviduct. They are not present in the eggs of many of the lower Invertebrata; these consisting merely of the parts which are formed within the ovarium.

795. The structure of the ovule in Mammals differs in no essential particular from that just described; but the yolk is much less in amount than in the ovules of Invertebrated animals, since only the very earliest stages of the development of the embryo are to take place at its expense; and it consists entirely of 'germ-yolk.' The vitelline membrane is of peculiar thickness and transparency; and as, when the ovum is compressed under the microscope, it is seen as a broad transparent belt (Fig. 194, *a*), it is commonly known as the *zona pellucida*.

796. A successive maturation and liberation of Ova take place in the adult females of animals generally, quite independently of sexual intercourse, at certain periods of special activity of the generative system. In most Fish and in some Reptiles, the ova are even discharged from the body of the parent whilst still unimpregnated; and although in Birds they are usually fertilized before being deposited, yet it is a matter of common occurrence for the hen of the domestic Fowls, if well supplied with food, to continue laying fully-formed eggs without the presence of the cock. If the ovary of a hen in this condition be examined, it is found to consist of a mass of spheroidal bodies of different sizes, loosely held together by connective tissues (Fig. 195). Each of these bodies consists externally of a vascular membrane, connected by a sort of pedicle with the general base of the whole; and through this pedicle it receives its supply of bloodvessels. This is lined by a delicate structureless membrane, the proper *ovisac*, the cavity of which is entirely filled by the ovum. The size of the ovisac is dependent on the amount of yolk accumulated in the yolk-bag, and when the full measure of this has been elaborated from the nutrient materials supplied by the blood distributed on the membrane enveloping the ovisac, the white assumes the form of a pear hanging into the peritoneal cavity by a slender footstalk. The envelopes then speedily thin-away at their most prominent part, until an opening is formed from which the ovum is discharged, to be received into the trumpet-shaped mouth of the oviduct, leaving the torn follicle (*a*), which gradually shrivels-up and disappears. The smaller ova

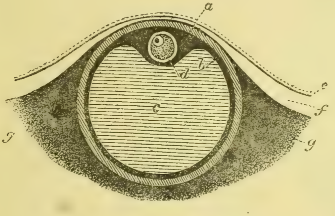
Fig. 195.*

* Ovarium of a Fowl, showing ovisacs containing ova in various stages of development; *a*, ovisac from which an ovum has just been discharged.

gradually enlarge in their turn, by the augmentation of their yolk; and in due time are successively discharged in like manner.

797. The relations of the Mammalian ovum to the ovarium, however, are somewhat different. Each ovum, as in the lower Vertebrata, is developed within an ovisac; and this is embedded in the *stroma* or fibroid parenchyma of the ovarium, of which the layer in immediate contact with the ovisac is somewhat differentiated by its membranous character and peculiar vascularity, forming what is known as the *outer* layer of the *Graafian follicle* (so named after its discoverer), the ovisac constituting its inner layer. The ovum, instead of being closely surrounded by the ovisac, is separated from it by a layer of minute granular cells, known as the *membrana granulosa* (Fig. 196, *b*). This layer is much thicker at the part of the ovisac nearest to the surface of the ovary. As the period approaches at which the

Fig. 196.*

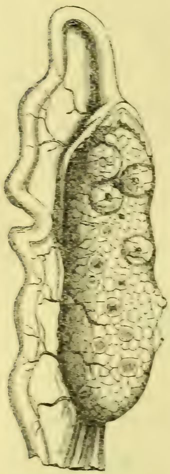


ovum is to be discharged, an effusion of serous fluid takes place into the interior of the ovisac (Fig. 196, *c*); and this pushes outwards the ovum, which becomes imbedded in the thickened portion of the membrana granulosa, now designated the *discus proligerus*, as shown at Fig. 196, *d*. In this manner the enlarged Graafian follicle comes to form a protuberance on the otherwise smooth surface of the ovarium (Fig. 197); and a progressive thinning-away of its envelopes takes place, until an aperture is formed, through which the ovum escapes into the peritoneal cavity, to be received into the fimbriated extremity of the Fallopian tube.—The Mammalian Ovarium may be seen, even in the fœtal animal, to contain immature ova enclosed within their ovisacs. It appears that, even during the period of childhood,

* Diagram of a Graafian Follicle near the period of rupture:—*a*, membranes of the follicle; *b*, membrana granulosa; *c*, fluid effused into the interior of the follicle; *d*, ovum; *e*, peritoneum; *f*, tunica albuginea; *g*, *g*, stroma of the ovarium.

there is a continual rupture of the ovisacs and a discharge of ova at the surface of the ovarium; but these ova never attain so high a degree of development as to become fit for impregnation. Their evolution takes-place more completely, as well as more rapidly, at the period of puberty, when there is a greatly-increased determination of blood to the genital organs, and a correspondingly augmented energy in their nutritive operations. At this epoch, the parenchyma of the ovarium is crowded with ovisacs; which are still so minute, that in the Ox, according to Dr. Barry's computation, a cubic inch would contain 200 millions of them. Some of those nearest the surface, however, are continually attaining increased development; and a rupture of some of the Graafian follicles, and a discharge of ova prepared for impregnation from the exterior of the ovarium, thenceforth take-place with more or less tendency to *periodicity*, during the whole time that the female is in a state of aptitude for procreation.

Fig. 197.*



798. In the Human female, the period of Puberty usually occurs between the 13th and 16th years. The difference in the time of its advent partly depends upon individual constitution, and partly upon various external circumstances, such as temperature, habits of life, &c. As a general rule, habitual exposure to a warm atmosphere, an inert life, sensual indulgence, and circumstances that excite the sexual feelings, favour the approach of Puberty; whilst a cold climate and a hardy life retard it. The appearance of the Catamenial discharge usually takes-place whilst the evolution of the genital organs is in progress: and it is a decided indication, when it occurs, that the aptitude for procreation has been attained. It is not unfrequently delayed much longer, however; and its absence is by no means to be regarded as a proof of inability to conceive. The Catamenial fluid, as it proceeds from the lining membrane of the Uterus, seems to be nothing else than blood; but in its passage through the vagina, this is deprived of its coagulating power by admixture with the vaginal mucus, which is remarkable for its very acid character. The appearance of clots in the discharge may usually be regarded as an indication that an excess of blood is escaping from the

* Ovarium of the Rabbit at the period of heat, showing various stages of the extrusion of ova.

uterine surface. In some cases of difficult Menstruation, which seem to depend upon a state of low inflammation in the Uterus, the fibrin has such a tendency to become organized, as to form shreds or layers of false membrane, which sometimes plug-up the os uteri.—It has been recently maintained, that this periodical discharge of blood from the lining membrane of the uterus is *dependent* upon the ovarian œstrum; but there seems adequate reason for the belief that the two phenomena, although usually consentaneous, are essentially independent; since each occasionally recurs without being accompanied by the other. The catamenial discharge ordinarily makes its appearance pretty regularly (save during pregnancy and lactation) at intervals of 28 days; but there are many females in whom its recurrence takes-place with no less regularity at shorter or at longer intervals. The duration of the flow, too, is subject to great variations; for in some individuals it does not last above a day or two, whilst in others it continues a week or more.

799. This flux of blood from the lining membrane of the Uterus is not confined to the Human female, as was formerly supposed; but occurs in some of the lower Mammalia in the state of *heat* or periodical aptitude for procreation, at which time the ovarium contains ova ready for impregnation. The chief peculiarity attending its appearance in the Human female, is its regular monthly return. In the natural condition of many of the lower Mammalia, as in Oviparous animals, the period of heat recurs at some one time of the year,—usually in the spring; or, in the smaller and more prolific species, from two to six times. And in those which have undergone a change by domestication, the recurrence is usually irregular, depending upon various circumstances of regimen, temperature, &c. The general analogy between the Menstruation of the Human female and the Heat of the lower Mammalia,—consisting in the peculiar aptitude for impregnation which then exists, in consequence of the maturation of ova in the ovarium,—cannot now be questioned; but it appears that, in the Human female, ova *may* be matured and impregnated at *any* part of the period which elapses between the occurrences of the Catamenial discharge; though it is certain that the aptitude for conception is much greater during the few days which precede and follow the menstrual period, than at any intervening time. The duration of the period of aptitude for procreation, which is marked by the continued appearance of the Catamenia, is more limited in Women than in Men; usually terminating at about the 45th year. It is sometimes prolonged, however, for ten or even fifteen years longer; but the cases are rare in which women above 50 years of age have borne children. There is usually no menstrual flow during pregnancy and lactation; in fact, the cessation of the Catamenia is usually one of the first signs

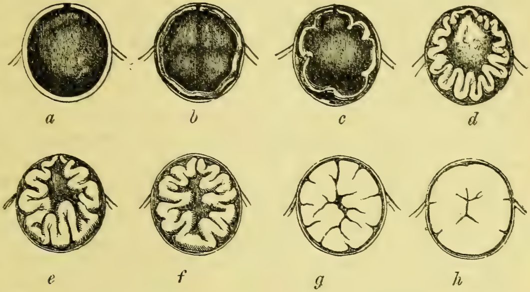
indicating that conception has taken-place. It is by no means uncommon, however, for them to appear once or twice subsequently to conception; and their appearance during lactation, especially if it be much prolonged, is still more frequent; hence it might be inferred that the continuance of lactation may not prevent a fresh conception, — which is found to be true in practice.

800. We shall now take a brief survey of the changes which occur in the Ovule when it is being prepared for fecundation; and of the principal features of its subsequent development.—The increase of size which is observable in the ovule that is being prepared for fecundation, is chiefly due to an augmentation in the substance of the yolk; and this also becomes more firm and granular than before. But the most curious change is that which takes place in the germinal vesicle; for this, although previously in the centre of the yolk, now moves-up towards the side of it which is nearest the surface of the ovary, and becomes flattened against the yolk-bag. At the same time it ceases to present its ordinary pellucidity, and becomes obscure; and this alteration appears to be due to the development of a brood of young cells in its interior. From the observations of Mr. Newport and others, it would seem probable that it then bursts and sets these free, so that they become diffused through the yolk; and as this change may happen before fecundation, it must be regarded as being preparatory to it, or at any rate as being independent of it.

801. The discharge of the Ovule from the ovarium (§ 797) is usually accompanied, in the Human female at least, with an effusion of blood into the cavity of the ovisac; and the coagulum which is left, at first of a blackish hue (Fig. 198, *a*) gradually loses its colouring matter, so as to acquire the aspect of a mere fibrinous clot, and is progressively removed by absorption (*b*, *c*, *d*). But an important change is at the same time occurring in the wall of the Graafian follicle itself; for, whilst the part with which the ovule comes in contact gradually thins-away, the outer or vascular layer of the remainder, especially on that side most deeply imbedded in the ovary, becomes much increased in thickness; and a great increase takes-place at the same part in the cellular layer that lines the ovisac, which presents a reddish glutinous aspect(*b*, *c*), This subsequently undergoes a still greater augmentation, and becomes more fleshy; projecting like a mass of granulations from the interior of the ovisac, and receiving blood-vessels which pass into it from the vascular membrane that surrounds it. At the same time, the wall of the Graafian follicle is thrown into wrinkles which are directed towards the interior (*d*, *e*), so as to occasion the contraction of the cavity; and thus (the blood-clot which previously filled it being gradually absorbed) it comes to be entirely filled with the new growth, the centre of

which is marked by a sort of stelliform cicatrix (g, h). This substance speedily becomes of a paler hue than at first, and is known from its colour as the *corpus luteum*.—The escape of the

Fig. 198.*



ovule from the ovarium involves processes which are essentially the same, whether it be impregnated or not; but the subsequent changes differ in the two cases, so that the corpus luteum which accompanies the pregnant state, is usually a much larger and more highly organized body than that which is found in the ovary of the unimpregnated female. The corpus luteum of Menstruation attains its maximum of development at about the end of the third week, at which time it is about three-quarters of an inch in diameter, its central clot reddish, and its convoluted wall pale. After this it begins to exhibit a retrogradation, its central coagulum being gradually absorbed and decolorized, while the convoluted wall undergoes a fatty degeneration which gives it a more decided yellow colour; and at the end of eight or nine weeks the whole body is reduced to an insignificant yellowish cicatrix-like spot, measuring less than a quarter of an inch in its longest diameter. The corpus luteum of Pregnancy, on the other hand, goes on increasing in size to the end of the fourth month, when it may measure seven-eighths of an inch in length by three quarters of an inch in depth; at this time the central coagulum is perfectly colourless and is reduced to less than a line in thickness, while the substance of the convoluted wall has greatly increased, and its colour has changed to a dull yellow. During the fifth and sixth months it undergoes but little change; but its size progressively diminishes during the remaining months of

* Successive stages of the formation of the Corpus Luteum in the Graafian follicle of the Sow, as seen in vertical section.

pregnancy, so that at the termination of gestation it is reduced to about half an inch in length and three-eighths of an inch in depth; and its retrogradation is so rapid after delivery, that at the end of eight or nine weeks only faint traces of it are distinguishable.*—It is obvious, then, that the presence of a small and imperfect corpus luteum in the ovary merely indicates that an ovum has been matured and discharged, and affords no evidence of impregnation or sexual intercourse. The presence of a large and characteristic 'corpus luteum,' on the other hand may be regarded as affording undoubted evidence that impregnation has taken-place.

802. The ovules discharged from the surface of the ovary by the process already described, whether sexual intercourse take place or not, are received into the Fallopian tubes, and by them conducted towards the Uterus. The propulsion of the large eggs of Birds and Reptiles through their oviducts is effected by a peristaltic contraction of the muscular walls of these canals; but that of the minute ovum of Mammals seems partly due to the action of the cilia lining the Fallopian tubes and their funnel-like commencements, which action, being directed from the ovary to the uterus, will aid the peristaltic movement which is observable during the period of heat. If in their course the ova should not receive the fertilizing influence, they appear soon to die and disintegrate; but if they should be impregnated by contact with the spermatic fluid, they almost immediately begin to undergo the first of those changes which tend to the production of a new organism. These changes may not only commence, but be carried on to their completion, even though the Ovum never reaches the uterus. Thus it may perhaps be fecundated without completely escaping from the Ovarium; and if retained and developed there, 'ovarian pregnancy' would occur. (Of the possibility of this occurrence, however, there is considerable doubt). Or, after having been set-free from the ovarium, it may escape into the peritoneal cavity instead of being received into the Fallopian tube; and if fertilized may undergo development in that cavity, so as to give rise to 'abdominal pregnancy.' Lastly, it may be arrested in its progress along the Fallopian tube; and being developed therein, 'tubal pregnancy' results. In each case the ovum draws its nutriment through a quasi-placental structure developed in connection with the organs in its vicinity.

803. Much discussion has taken place with regard to the exact point at which the fertilization of the ovule is effected; but this does not seem to be a matter of much consequence, as we find the order of the different steps to vary considerably in different classes of animals. Thus in many aquatic Mollusca, and even in a large

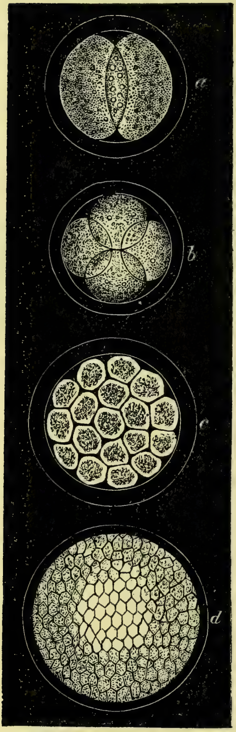
* See Dr. Dalton's Prize Essay 'on the Corpus Luteum of Menstruation and Pregnancy,' Philadelphia, 1857; and his 'Human Physiology,' 3rd Ed. 1864.

proportion of the class of Fishes, there is no act of copulation whatever; but the spermatic fluid emitted by the male is diffused through the water, and fertilizes the ova which have been deposited by the female in his neighbourhood. In the Frog, again, and in other Reptiles, the spermatic fluid is emitted upon the ova by the male, at the time that they are being extruded by the female. In many Insects and Crustacea, in which a single congress often serves to fertilize many thousand eggs, the deposition of which occupies a period of several weeks or months, the spermatic fluid is received and stored-up in a saccular dilatation of the oviduct of the female, which is termed the *spermotheca;* and in this manner it serves to impregnate the ova as they are successively developed and conveyed to the outlet of the oviduct. In Birds, we find that ova are often set-free from the ovarium in a state of full maturity, but without fertilization; and that they receive their additional layer of albumen and their shelly envelope in passing down the oviduct, so as, at the time of their deposition, to differ in no obvious particular from fertile eggs. It is doubtful in regard to Mammalia, whether the act of fertilization ordinarily occurs before the ovum has been completely extricated from the ovisac, or subsequently to its finally quitting the ovarium and being received into the Fallopian tube. Certain it is that the spermatozoa frequently, if not invariably, find their way to the surface of the ovary; and it seems on the whole most probable from the phenomena of 'extra-uterine fœtation' just referred-to, that the fertilization of the ova usually takes-place before they have entirely escaped from the ovisac, or whilst they are still in the commencement of the Fallopian tube.

804. Everything indicates that the contact of the Spermatozoa with the Ovule is the one thing needful in the act of fecundation; and the experiments and observations of the late Mr. Newport on the impregnation of the ova of the Frog, leave no reasonable doubt as to the essential similarity of the process in Animals to that which occurs in Cryptogamia whose sperm-cells produce self-moving 'antherozoids' (§ 780). For the spermatozoa imbed themselves in the gelatinous envelope of the ovum in a few seconds after they come into contact with it; they then make their way through the vitelline membrane into the interior of the ovum, where they undergo a gradual diffluence: and thus the product of the sperm-cell is enabled to mingle with that of the germ-cell, so as to lay the foundation of a germ,—the Spermatozoon being nothing else than an embodiment of the fertilizing material developed within the sperm-cell, which is endowed with a temporary power of movement (analogous to that of cilia) in order that it may find its way to the Ovum. It has been ascertained by Mr. Newport, that spermatozoa whose spontaneous motility has ceased, no longer possess the fecundating power.

805. *Development of the Embryo.*—The first change which can be observed to be consequent upon fecundation of the Mammalian ovum, is the 'segmentation' of the yolk; the entire mass of which, though previously compact and uniform, resolves itself, first into two, then into four, (Fig. 199, *a*, *b*), then into eight segments; each segment containing a transparent vesicle, which may be surmised to be a descendant of the original germ-cell. By a continuance of the same process (*c*, *d*), the whole cavity of the vitelline sac or zona pellucida becomes occupied by spherical particles of yolk, the aggregation of which gives it a mulberry-like appearance; and by its further continuance, the component segments becoming more and more minute, the mass comes to present a uniform finely-granular aspect. At this stage it does not appear that the several segments of the yolk have a distinct enveloping membrane; but an envelope is now formed around each of them, converting it into a cell of which the included vesicle forms the nucleus. This happens first to the peripheral portion of the mass; and as its cells become fully developed, they arrange themselves at the surface of the yolk into a kind of membrane, at the same time assuming a pentagonal or hexagonal shape from mutual pressure, so as to resemble pavement-epithelium. As the globular masses of the interior are gradually converted into cells, they also pass to the surface and accumulate there, thus increasing the thickness of the envelope already formed by the more superficial layer of cells; while the central part of the yolk-mass remains as a clear fluid, which seems to be the produce of the liquefaction of some of the

Fig. 199.*



* Progressive stages in the segmentation of the vitellus of the *Mammalian Ovum* :—*a*. its first division into two halves; *b*, subdivision of each half into two; *c*, *d*, further subdivision, producing numerous segments.

interior spherules, with the addition of albuminous fluid absorbed from without. By this process, the external part of the yolk is converted into a kind of secondary envelope, constituting the *germinal* or *blastodermic membrane;* and in this there may soon be distinguished two layers, of which the outer is composed of smaller and more compact cells, whilst the cells of the inner are larger and looser. The ovum then presents the appearance of a globular sac, the walls of which consist of three concentric layers, lying in contact with and freely inclosing each other; viz.: 1st, the structureless vitelline membrane; 2nd, the external layer of the blastodermic membrane; and 3rd, its internal layer. The cavity enclosed by the latter is occupied, as already mentioned, by a transparent fluid. The outer or *serous* layer subsequently gives origin to the central parts of the nervous system, to the higher organs of sense, and to the epidermis and its appendages. The inner layer subsequently divides into two laminæ, of which the most internal, termed the *mucous* or *glandular* layer, gives origin to the epithelial layer of the alimentary canal and of the glands connected with it; whilst from the intervening or *vascular* layer, which consists of several strata, the bones, muscles, generative organs, and vascular apparatus are developed.—The 'segmentation' now described may be well seen and studied in the egg of the Frog, in which, as in the Mammalian ovum, the entire yolk serves as the foundation of the embryonic structure. In the egg of the Bird, on the other hand, the process of segmentation is limited to a very small fraction of the whole vitellus, the great mass of this being of the nature of 'food-yolk' (§ 794), and being destined for the subsequent nutrition of the embryo that is originally formed by the segmentation of the 'germ-yolk' only; the mass of cells thus produced being known as the *cicatricula* or 'germ-spot,' which may be distinguished as a whitish film on the surface of the yolk, always occupying such a position that it is brought into the nearest possible proximity to the body of the parent from which its heat (or developmental force, § 59) is derived.

806. Thus the first development of the Vertebrate embryo is into a sac, enclosing the store of nutriment that has been prepared for it,—in fact, a stomach; and we shall presently see that it is by absorption through the wall of this sac, that the nutrient materials it encloses are prepared for being appropriated to the development of the more permanent part of the fabric, which is to be evolved from a certain part of its surface. But we may here stop to notice the interesting fact, that the development of the ovum in the *lowest* classes of animals may almost be said to cease at this point; the external layer of the germinal membrane remaining as the integument, the internal layer becoming the lining of the stomach, and the space occupied by the yolk forming

the digestive cavity, into which an entrance or *mouth* is formed by the thinning-away of the germinal membrane at a certain point, round which *tentacula* or prolonged lips are usually developed. This is the essential part of the history of development in the simpler Polypes; and we see how remarkably it corresponds with the history of development of the lower Cryptogamic plants, in which the first-formed membranous expansion, or primary frond, remains to represent the permanent leaf.—In Mammals, on the other hand, the greater part of the germinal membrane, and of the cavity which it encloses, has a merely temporary purpose; being cast off, when it has performed its function, like the cotyledons of Flowering Plants.

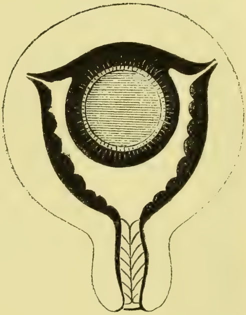
807. During the time which is occupied by these important changes, the Ovum passes through the Fallopian tube, and makes its way into the Uterus. During its transit through the Fallopian tube, the Mammalian ovum,—like the ovum of Birds in its passage through the oviduct,—receives an additional layer of albuminous matter secreted from the walls of the tube; and upon this there seems to be poured-out a plastic exudation, in which a new envelope takes its origin. This envelope, however, instead of being merely protective, — like that which, when consolidated by the deposition of particles of carbonate of lime in the meshes of its fibrous network (§ 188), forms the 'shell' of the Bird's egg,—undergoes a much higher organization, and becomes the medium through which the whole subsequent nutrition of the embryo is drawn in from its parent. What is called the *Chorion* seems to be formed by the coalescence of this new deposit with the vitelline membrane or 'zona pellucida,' which henceforth ceases to be recognizable as a distinct investment; its entire surface being rendered villous by the growth of a number of minute processes which give it a spongy or shaggy appearance (Fig. 201). These processes (which are composed of nucleated cells) serve as absorbing radicles which draw-in the fluids afforded by the parent; and they thus make up for the early exhaustion of the small supply of nutritious matter stored up in the ovum itself. The contained embryo appropriates the fluid which is thus imbibed, by simple absorption through its surface; and thus it is nourished, until a more special provision for its development comes into action.

808. A very important change is at the same time taking place in the Mucous membrane lining the Uterus; by which it is enabled to afford the supply of nutriment required by the embryo in this early stage, and is prepared for taking part in the development of the *Placenta*, through which organ the fœtus is provided with nutriment in a more advanced period of development. This mucous membrane, in its natural condition, presents on its free surface the orifices of numerous cylindrical follicles, which are

arranged parallel to each other and at right angles to the surface; and in the spaces between these follicles, the blood-vessels form a dense capillary network. When impregnation takes-place, the membrane swells and becomes lax; its capillaries increase in size; the follicles are developed into glandular cavities, and become turgid with a white epithelium; and the interfollicular spaces are crowded with nucleated cells, which fill-up the meshes of the capillary network. In this peculiar condition, the uterine mucous membrane is termed the *Decidua*. At a later period, the decidua is found to consist of two distinct layers; the *decidua vera*, lining the uterus; and the *decidua reflexa*, covering the exterior of the ovum. Much discussion has taken place with regard to the mode in which the decidua reflexa originates; but the view originally put-forth by Coste is the one now generally received. He considers that the ovum, on its entrance into the uterine cavity, is partly imbedded in its thick vascular lining membrane, and that this swells-up around it like the granulations around the pea in an issue (Fig. 200); so that at last the ovum becomes completely invested by the special envelope thus formed, which closes-in around it so as to constitute the decidua reflexa, and which is at first not in contact with the decidua vera at any part save where it has sprung from this (Fig. 201). As the ovum increases in size

Fig. 200.*

Fig. 201.†



the decidua reflexa grows with it, and is thus gradually brought into contact with the decidua vera which lines the Uterus, the

* Diagram of the formation of the Decidua reflexa by projecting folds of the decidua vera (represented by the black shading) growing up around the Ovum.

† Diagram showing the completion of the Decidua reflexa by the meeting of the folds that have grown up around the Ovum; and the origin of the villi from the Chorion investing the latter.

cavity between them being obliterated; and at a later period the two coalesce, so that they become no longer distinguishable from each other (§ 822).

809. When the ovum has arrived in the Uterus, therefore, and the villous tufts of its Chorion are developed, these come into contact, in the first instance, with the epithelial layer which intervenes between them and the vascular decidua. Through this cellular membrane, therefore, the ovum must derive its nutriment from the vascular surface; and it cannot be deemed improbable that its office is to draw from the subjacent vessels the materials which are to serve for the nutrition of the ovum, and to present it to the villous tufts of the Chorion. Each of these, as already mentioned (§ 807), is composed of an assemblage of nucleated cells, which are found in various stages of development; and the villus seems to elongate by the development of new cells at its free extremity, whilst, like the spongiole of the plant, it draws-in nutriment from the soil in which it is imbedded. On the other hand, the Decidua at this early period appears to be actively employed in preparing nutriment for the embryo; for its cellular layer is so abundant as to form a bed into which the tufts of the chorion are received; whilst its follicles are enlarged into glandulæ of sufficient size to allow these villi (in some Mammals at least) to extend themselves into their interior.—In its earliest grade of development, as already remarked, the chorion and its villi contain no vessels; and the fluid drawn-in by the tufts is communicated to the embryo by the absorbing powers of its germinal membrane. But when the tufts are penetrated by blood-vessels, and their communication with the embryo becomes much more direct, the means by which they directly communicate with the parent are found to be essentially the same;—namely, a double layer of cells, one layer belonging to the fœtal tuft, the other to the vascular maternal surface (§ 818).

810. We now return to the Ovum itself; and shall trace its general history up to the period at which the vascular system of the embryo is so far developed as to enable it to take part in the formation of the Placenta.—The first stage in embryonic development, which is common to all Vertebrated animals, consists in a thickening and condensation of a certain part of the blastodermic membrane (§ 805), which is termed the *area germinativa* or embryonic spot (Fig. 202). This spot is oval in form, and its peripheral portion is more opaque than the surrounding membrane; but this opaque border encloses a clear space, named the *area pellucida;* and in the centre of this space is seen a longitudinal line marking a furrow that extends nearly from one extremity to the other, which marks the first formation of the vertebral column, and is termed the *primitive trace.* The relation of this embryonic foundation to the other parts of the Ovum, is

best shown in a vertical section (Fig. 203); the thickest portion of the embryonic spot *c* is its anterior or cephalic extremity, while the thinner part forms its posterior or caudal extremity.—The shallow groove or furrow is the first indication of what is

Fig. 202.*

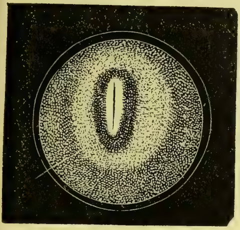
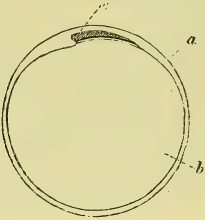


Fig. 203.*



afterwards to become the crano-spinal canal for the reception of the neural axis; and the completion of this into a tube is the next principal step in the developmental process. The borders of this groove are formed by two nearly parallel vertical plates or ridges (Fig. 204, 2, 2,) which are termed the *laminæ dorsales;* these rise more and more from the general surface, so as to deepen the groove between them; and the summits of the ridges then arch-over towards each other, so as at last by their meeting to convert the groove into a canal (Fig. 205, 2, 2,). This closure takes place from behind forwards; the narrow posterior portion of the tube, which is to hold the Spinal Cord, being first completed; and its anterior dilated portion, within which are developed the various component segments of the Encephalon (Fig. 229), remaining open to a much later period. Beneath the Spinal Canal there is now observed a distinct cylindrical rod (Fig. 205, 4) of nucleated cells (Fig. 13), termed the *chorda dorsalis,* which occupies the place afterwards taken by the bodies of the vertebræ; this retains its embryonic type in many of the lower Fishes, which never possess a true vertebral column. The elements of the vertebræ are afterwards developed in a fibrous membrane with which the chorda dorsalis subsequently becomes invested; their 'bodies' being first formed as rings, from which the 'neural arches' pass upwards into the laminæ dorsales, whilst the 'visceral arches' (consisting of the transverse processes and ribs) pass downwards into the 'abdominal plates' to be next described.

811. Whilst the neural canal is being completed above, a great

* Commencement of formation of Embryo in the embryonic spot of the blastodermic membrane, enclosing the area pellucida and primitive trace.

† Section of Ovum, showing within its external investment the blastodermic vesicle *a*, its cavity *b*, and the embryonic spot *c*, divided longitudinally.

extension is taking place below from the lateral margins of the embryonic spot, which grow downwards and outwards, so as to

Fig. 204.*

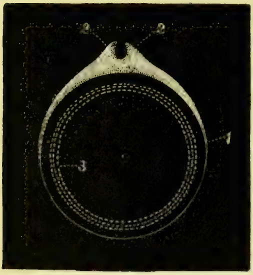
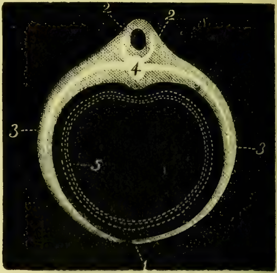


Fig. 205.†



spread themselves more and more over the cavity of the blastodermic vesicle (Fig. 204, I, I). These 'abdominal plates,' in the ovum of the Frog, gradually extend themselves over the entire surface of the ovum, so as at last to meet on the side of the blastodermic vesicle exactly opposite to the embryonic spot (Fig. 205, I), and to enclose the whole vitelline mass, which is partly composed of the remains of the original vitellus and partly of albuminous fluid that has been absorbed from without; and by the appropriation of this material through the internal layer of the blastodermic membrane, the entire contents of the ovum are directly converted into the materials of the embryonic structure, without the development of any of those accessory organs which we shall find to exist in Birds and Mammals. In these classes, as in most Fishes (Fig. 206), the abdominal plates extend themselves only over a small part of the vitelline mass, and then bend inwards so as to form a constriction,—pinching off (as it were) the portion of the blastodermic vesicle which is to be received within the body of the embryo, and which is to be employed in the formation

Fig. 206.‡

* Transverse section of Ovum of Frog, showing the formation of the Spinal canal;—1, External layer of blastodermic membrane; 2, 2, laminæ dorsales proceeding from it; 3, internal layer of blastodermic membrane.

† Transverse section of more advanced Ovum of Frog, showing completion of Spinal canal:—1, Umbilicus, or point of union between abdominal plates; 2, 2, Dorsal laminæ inclosing dorsal plates; 3, 3, abdominal plates; 4, Section of chorda dorsalis; 5, internal layer of blastodermic membrane.

‡ Embryo Fish, showing the incipient separation of the Umbilical Vesicle.

of its permanent alimentary canal, from the remaining portion which is shut out of the abdominal cavity altogether, and is, in many instances, cast off when emptied of its contents. The outer wall of this sac-like appendage, which is termed the 'umbilical vesicle,' is formed by a portion of the external layer of the blastodermic membrane, which is continuous with the abdominal integument of the embryo; and its cavity is lined by a portion of the internal layer of the blastodermic membrane, continuous with that which ultimately becomes the mucous membrane of the alimentary canal. A vascular layer is subsequently formed between these; and a very beautiful network of vessels makes its appearance, in which the blood is distributed over the surface of the umbilical vesicle, apparently with a view to its aëration (§ 814). As the contents of this vesicle are progressively appropriated to the nutrition of the embryo, being received into the alimentary canal by a narrow opening which still connects the two portions of the originally undivided cavity, the vesicle itself shrinks; and is usually, in Fish as in Birds, drawn at last into the abdominal cavity, the walls of which close over it.—In the Human subject, however, as in Mammals generally, the umbilical vesicle is far more completely separated from the body of the embryo, than it is in the case just described. There is at first, as in the lower Vertebrata, a free communication between the cavity of the vesicle and the alimentary canal of the embryo (Figs. 209—211); but the constriction which at first only partially separated them at last becomes so complete that the passage between them is entirely obliterated, what was at first a canal becoming an impervious cord. This cord elongates, and becomes a slender pedicle passing out from the abdomen of the embryo, and bearing the umbilical vesicle at its extremity (Fig. 207). At a later period it comes to contain the Omphalo-mesenteric vessels which convey the blood of the embryo to be distributed on the wall of the vesicle (§ 815); and it is by absorption through them, that the contents of the vesicle are applied to the nutrition of the embryo. The Umbilical vesicle is distinctly visible as an appendage to the Human embryo as late as the end of the third month: after that period it diminishes in size, and is gradually lost in the advancing development of the neighbouring parts.

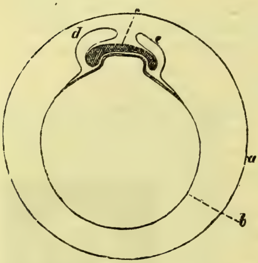
Fig. 207.*

812. Two accessory organs are formed at an early period of the evolution of the Ovum, in the higher Reptiles, and in all Birds and Mammals, of which there is no trace in the ovum of

* Human Embryo, with appended umbilical vesicle, about the fifth week.

Fishes or of Frogs, and which are subservient to the more advanced development which the embryo of the higher Vertebrata undergoes before it comes forth into the world. These two organs, the *Amnion* and the *Allantois*, are always found together, the one being never present without the other; they make their first appearance nearly at the same period, the Amnion being rather in advance; and it would seem as if, while the *Allantois* is an organ developed with special reference to the respiration of the embryo, the development of the *Amnion* has reference mainly to the formation of the Allantois. The Amnion is formed from the *external* layer of the blastodermic membrane, and the Allantois from its *internal* layer; and the production of the former opens a passage (so to speak) for the latter, through which it may make its way to that contact with the external envelope of the ovum, which is requisite for its performance of the important function committed to it.—The formation of the *Amnion* commences soon after the body of the embryo has begun to be formed in the 'embryonic spot'; and it consists in a rising-up of a double fold of the external layer of the blastodermic membrane around the margin of the embryo, which thus appears sunk within a sort of ridge. This ridge, consisting of the double amniotic folds, gradually increases in elevation; and an arching-over takes place in it from all sides (Fig. 208), so that the folds at last meet each other. Previously to this meeting, however, the outer fold has extended itself so greatly as to come into close proximity with the outer envelope of the Ovum, whilst the inner overlies the body of the embryo, as is seen in Fig. 209. These amniotic folds at last meet each other over the back of the fœtus at a point called the 'amniotic umbilicus'; and the membranes of the two fuse together so as to form a single partition (Fig. 210, *c*,) running from the inner to the outer lamina of the amniotic folds, and separating the anterior and posterior portions of the cavity that intervenes between them. This partition soon after atrophies and disappears; and the two laminæ are henceforth disconnected, the inner one forming the investment to the body of the embryo which is henceforth known as the *Amnion* (Fig. 210, *b*), whilst the outer one coalesces so completely with the external

Fig. 208.*



* Diagram of Mammalian Ovum, showing the incipient formation of the Amnion:—*a*, chorion; *b*, blastodermic vesicle; *c*, embryo; *d*, *e*, amniotic folds.

investment of the Ovum, as to be henceforth unrecognizable as a distinct membrane.

813. The *Allantois* (Fig. 209, *c*) commences as a sort of diverticulum from the lower extremity of the Alimentary canal, which is itself, as just shown, a portion of the blastodermic vesicle pinched-off, as it were, from the remainder. Its cavity is continuous with that of the intestine; and it is furnished with blood-vessels derived from those of the intestinal walls, the development of which will be presently described. Whilst the Amniotic folds are undergoing extension, the Allantois, which rapidly increases in size, insinuates itself between them (Fig. 210), and soon comes into contact with the external amniotic fold, which has by this

Fig. 209.*

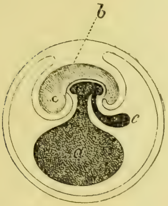
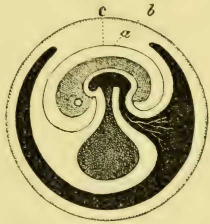


Fig. 210.†



time coalesced with the general investment of the Ovum. It then begins to extend itself in every direction, growing round the interior of the ovum in such a manner as to form a complete lining to it (Fig. 211); and the two extremities of its flattened sac, coming into contact with each other over the back of the embryo, fuse together just as those of the Amnion had previously done. The further history of the Allantois presents an important difference in Oviparous and Viviparous animals, which is related to the other provisions made for the nutrition and respiration of the embryo in the more advanced stages of its development.

814. In all Oviparous Vertebrata, the store of Yolk originally laid-up in the egg, with the addition of the albuminous secretion formed around the yolk-bag in its passage through the oviduct, affords material sufficient for the entire evolution of the embryo. But in the Mammalian ovum, the nutriment thus supplied is sufficient only for the very earliest stages of embryonic development; and, as we have already seen, a special provision is made

* Diagram of Ovum, showing the formation of the *Amnion*, and the commencement of the development of the *Allantois*: *a*, umbilical vesicle; *b*, embryo; *c*, allantois.

† Diagram of Ovum, showing completion of *Amnion*, and extension of the *Allantois*; *a*, inner lamina of amniotic fold, forming amnion; *b*, outer lamina coalescing with external envelope; *c*, junction between amniotic folds.

in the secreting action of the glandular Decidua of the mother, and in the absorbent action of the villous Chorion of the ovum, for supplementing this, until the further development of the embryo shall have enabled a still more elaborate provision to be brought into action.—But again, the embryo like the adult, has need of Respiration, in order that the carbonic acid set-free in the nutritive operations may be removed from its fluids. In Fishes, the surrounding water acts with sufficient power upon the vessels of the yolk-bag to produce the required aëration, up to the time when the gills of the young animal are ready to come into play. But in the higher oviparous animals, whose development proceeds further before they leave the egg, it is the Allantois which serves this purpose, lying everywhere immediately beneath the shell-membrane, and receiving the direct influence of the air that penetrates the latter. It is thus the temporary lung of the air-breathing oviparous animal; and it serves for the aëration of its fluids, up to the time when it quits the egg. In the ovum of the Mammal, on the other hand, the function of the Allantois is only temporary; being essentially that of conveying the vessels of the embryo to the chorion, with which the external layer of the Allantois coalesces (Fig. 212); and these vessels, sprouting into the villi of the chorion (§ 818), subsequently become the channels at the same time of the nutrition and of the respiration of the embryo, in the manner to be hereafter described. The Allantois of the Mammal, when it has fulfilled this function, ceases to present itself as a distinct sac; its two layers coming into contact fuse together, and its cavity becomes obliterated. This takes place at a very early period in the

Fig. 211.*

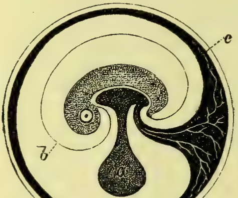


Fig. 212.†

* Diagram of Ovum, showing the completion of the Allantois, *c*, which entirely surrounds the Amnion, *b*, and lines the external envelope.

† Human Ovum, about the end of the first month, showing the coalescence of the Allantois with the inner side of the chorion, 3, and the villosities proceeding from its surface; 1, umbilical vesicle; 2, amnion.

Human embryo, in which it never has the character of a distinct sac. In the saccular form which it presents in some of the lower Mammalia, however, it serves as a temporary receptacle for the urinary secretion, formed in the first place by the Corpora Wolffiana, and afterwards by the true Kidneys. The permanent urinary bladder is commonly said to be the lower portion of the Allantois, pinched-off (as it were) from the rest; but this organ really originates in the upper part of the 'urogenital sinus,' into which, in the early Human embryo, as in the lower Mammalia, the ureters and the sexual ducts discharge themselves in both sexes alike; and the urachus or suspensory ligament of the bladder is the shrivelled remnant of a duct, by which the 'urogenital sinus' originally communicated with the Allantois.

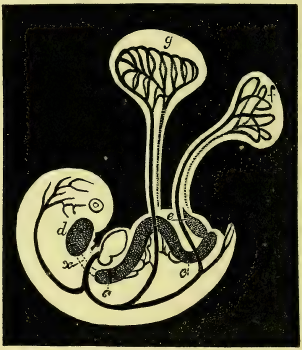
815. We have now to describe the origin and development of the *Vascular System*, which very early takes a most important share in the nutrition of the embryo; the vessels formed in the substance of the Blastodermic membrane, in the manner already described (§ 323), serving to take-up the nourishment supplied by the yolk, as well as that derived externally through the chorion, and to convey it through the tissues of the embryo. These vessels are first seen in that part of the vascular lamina of the

Fig. 213.*

* Vascular area of *Fowl's Egg*, at the beginning of the third day of incubation;—*a*, *a*, yolk; *b*, *b*, *b*, *b*, venous sinus bounding the area; *c*, aorta; *d*, punctum saliens, or incipient heart; *e*, *e*, area pellucida; *f*, *f*, arteries of the vascular area; *g*, *g*, veins; *h*, eye.

blastodermic membrane which immediately surrounds the e bryo; and they form a network bounded by a circular chann which is known under the name of the *Vascular Area* (Fig. 21 and which gradually extends itself until the vessels spread over t whole of the blastodermic membrane. This network of vess

Fig. 214.*



serves to receive the nutritious matter contained in the yolk-ba and to convey it to the embryo; but the act of absorption seer to be performed here as elsewhere, by cells, a layer of whi always intervenes between the vascular layer and the yolk itse These cells probably correspond in function with those of t villi of the intestinal canal in the adult (§ 494); as the vessels the yolk-bag, or temporary digestive cavity, represent those the alimentary canal to be afterwards developed from a portion it. The vessels of the Umbilical vesicle (Fig. 214, *g*), whi represents in Mammals the yolk-bag of Birds, enter the embr at the point that afterwards becomes the umbilicus, and a known as the *Omphalo-Mesenteric*, *Meseraic* or *Vitelline* vessels. . first there are two Arteries and two Veins; but one trunk of ea kind is soon obliterated, and the vitelline circulation is thenc forward carried on by a single Artery and Vein (Fig. 21 *q*, *r*). At this period, the Intestinal canal, entirely separat from the yolk-bag, has the form of a cylindrical canal, closed each end (Fig. 214, *c*, *c*), but not yet included within the abdomir

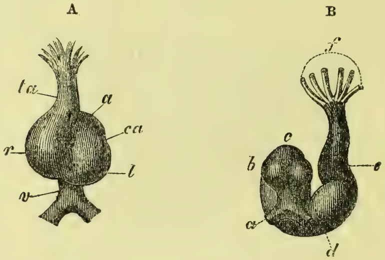
* Diagram of Early Embryo, showing the formation of the Intestinal tu and the commencement of the Circulating apparatus;—*c*, *c*, Intestinal tut *d*, Pharynx; *e*, Urinary bladder; *f*, Allantois; *g*, Umbilical vesicle; *x*, pl of formation of œsophagus.

valls, which do not meet along the median line until some time fterwards. With the formation of the intestine, the omphalo-nesenteric vein of the right side disappears, the left alone remain-ng, which is soon joined by a small mesenteric vein from the ntestine. Before this is accomplished, however, the Allantois as been developed; and two *Umbilical* veins pass forwards from it o open into the common trunk of the omphalo-mesenteric veins Fig. 214). The Umbilical veins (Fig. 216, *o*, *o'*) rapidly increase in ize, and come to preponderate so much over the remaining Omphalo-nesenteric vein (*q*, *q*), that the latter now appears to be merely a ributary branch. As the Liver becomes developed upon a diverti-ulum from the wall of the intestine (Fig. 165), it surrounds the runk formed by the confluence of these vessels, now known as he Umbilical vein; and this soon gives off a two-fold system of ubes within that gland; the one set, termed the *Venæ hepaticæ dvehentes*, conveying the blood to the liver itself; the other, ermed the *Venæ hepaticæ revehentes*, returning the blood from he gland-substance to the part of the Umbilical vein between he liver and the heart, afterwards known as the *Hepatic* vein. The right Umbilical vein now disappears; and the blood return-ng from the fœtal portion of the Placenta, which is developed rom the vessels of the Allantois, traverses the left vein alone, which soon takes up an entirely median position; and the om-halo-mesenteric vein, with branches derived from the Intestine which increase in relative importance with its development), ltimately comes to open into the right *vena hepatica advehens*, nd thus constitutes the origin of the Portal vein. The portion of he Umbilical vein which lies between the two systems of epatic vessels, and which conveys a portion of the blood directly nwards to the heart without distributing it to the liver, remains ervious through the whole of fœtal life, and is known as the *uctus venosus* (Fig. 225, 5).

816. The formation of the *Heart* takes-place in a thickened ortion of the Vascular layer, by the liquefaction of the interior f a mass of cells, of which the exterior constitute the first walls f the cavity. These gradually acquire firmness and consistency, nd are endowed with a contractile power that enables them to xecute regular pulsations. In this early condition, the heart is nown as the *punctum saliens* (*d*, Fig. 213). The first appear-nce of the heart in the Chick is at about the 27th hour; the me of its formation in Mammalia has not been distinctly ascer-ained. In its earliest form, it has the simple character which presented by the central impelling cavity of the lower Inver-brata; being a mere prolonged canal, which at its posterior xtremity receives the veins, and at its anterior sends forth the teries. Between the 15th and 18th days in the Human embryo, becomes doubly bent upon itself (Fig. 215, A, B), one bend of

the loop corresponding to the arterial, the other to the venous portion. After this, two slight enlargements (B, *b*) are observed

Fig. 215.*



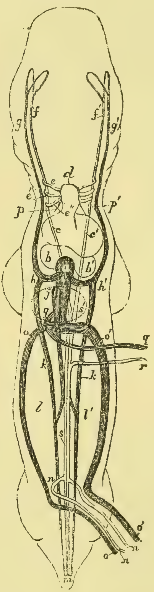
in the venous bend; and the arterial bend separates into two parts by a long line of division. The two enlargements represent the auricles (which at this period freely communicate with each other), and receive the Omphalo-mesenteric veins (B, *a*); and they open above into the atrium (*c*), which leads to the right ventricle (*d*), and this again into the aortic bulb (*e*), from which arises the truncus arteriosus (A, *ta*) that gives off five pairs of aortic arches (Fig. 217, A).

817. The early condition of the *Arterial* system of the embryo is very nearly the same in all Vertebrata, and closely corresponds with that which remains permanent in Fishes (§ 558). The truncus arteriosus, by which the blood issues from the heart (Fig. 216, *d*), subdivides into a series of arches (*e*, *e'*, *e''*), like the branchial arches of fishes, on either side; of these there are usually five pairs in all, but the highest generally become impervious before the lowest are developed. By the coalescence of these are formed above the arterial trunks, *f*, *f*, which represent the common carotids, and below the descending aorta, *s'*, *s*, from which are given off the umbilical arteries *n*, *n'*, proceeding to the allantois, and the omphalo-mesenteric artery, *r*, distributed on the wall of the umbilical vesicle.—The following is the mode in which the permanent arterial system is developed in the Chick out of this primitive and general type. The first two pairs of arches (Fig. 217, B, 1, 1', 2, 2') are wholly obliterated; but those of the

* Heart of Embryo Rabbit, seen from front at A, and from back at B:—A, *ta*, truncus arteriosus; *l*, left ventricle; *r*, right ventricle; *a*, auricle; *v*, venous sinus:—B, *a*, omphalo-mesenteric veins; *b*, auricles; *c*, atrium; *d*, right ventricle; *e*, bulbus arteriosus *f*, aortic arches.

third pair remain to form the common trunks which, in Birds, give off on either side the subclavian arteries b, b', and the carotid arteries, c, c'. At about the beginning of the sixth day of incubation, the truncus arteriosus, a, becomes flattened, and its opposite sides adhere, so as to divide it into two tubes running side by side. Of these, one communicates with the left, and the other with the right ventricle. The former, which subsequently becomes the ascending Aorta, A′, is continuous with the fourth branchial arch on the right side only; and from this the two *arteriæ innominatæ* formed by the third branchial arches take their origin by distinct trunks. This arch gradually increases in size, so as to form the freest channel of communication between the heart and the descending aorta; becoming in fact, the 'arch of the aorta.' The trunk P′, on the other hand, which is connected with the right ventricle, and which subsequently becomes the Pulmonary artery, transmits its blood through the fourth arch of the left side, 4′, and the fifth arch, 5, of the right side, the two primary tubes twisting round each other; but the fifth arch of the left side, 5′, now ceases to convey blood. From the two trunks, 4′, 5, which still discharge their blood into the descending aorta, the pulmonary arteries P, P, branch-off as the lungs are developed; and the prolongation, 10, of the right side soon afterwards becomes impervious. But the prolongation, 9, on the left side still remains open, and passes into the descending aorta of that side; so that a portion of the blood sent from the right ventricle is transmitted directly to the descending aorta, through this *ductus arteriosus*, just as in the adult Crocodile (§ 563). After

Fig. 216.*

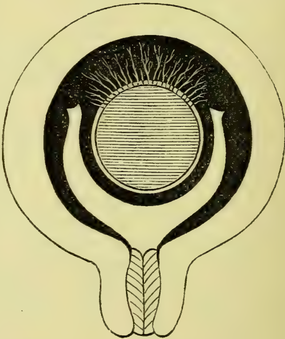


* Diagram of the Circulation in the Human Embryo, as seen from the front, at the commencement of the formation of the Placenta:—a, venous sinus, receiving all the systemic veins; b, right auricle; b', left auricle; c, right ventricle: c', left ventricle; d, bulbus arteriosus, subdividing into e, e', e'', branchial arches; f, arterial trunks formed by their confluence; g, g', venæ azygos superior; h, h', confluence of superior and inferior azygos; i, vena cava inferior; k, k', venæ azygos inferior; l, l', their anastomosis with descending cava; n, n', umbilical arteries; o, o', umbilical veins; q, q, omphalo-mesenteric vein; r, omphalo-mesenteric artery; s, s', descending aorta.

Mammalia which are designated as *non-placental*, no closer relation is formed between the vascular systems of the fœtus and the mother, than is established by this impinging of the vascular villi of the Chorion against the vascular Decidua of the mother; but where a *Placenta* is formed, the arrangement becomes much more complicated. An intermediate stage is presented by the Ruminants and some other Mammalia; in which the decidua puts forth vascular tufts, which interlace with the fœtal tufts, without actually communicating with them; the bodies thus formed, which are scattered over the whole surface of the Chorion, are termed *cotyledons*. But in the higher Mammals and in Man, each embryo has but a single organ of this nature, the *Placenta*, which attains a large size and presents a remarkably complex structure. It is essentially composed, however, of a *fœtal* portion, which consists exclusively of the elongated and subdivided villi of the Chorion; and of a *maternal* portion, consisting of an extension of the vascular system of the Uterus, which carries before it the Decidual membrane.

Fig. 218.

Fig. 219†.



819. The *fœtal* portion of the Placenta contains the branches of the umbilical vessels; which subdivide at the point at which they enter the mass, and form, by their minute ramifications, a large part of its substance. Each villus contains a capillary ves-

* Human Ovum at the end of the third month, showing the placental portion of the chorion distinguished from the rest.

† Diagram of Uterus at the time of the formation of the Placenta by the united development of a portion of the Decidua and of the villous tufts of the Chorion.

sel, which forms a series of loops (Fig. 220), communicating with an artery on the one side, and with a vein on the other; but the

Fig. 220.*

same capillary may enter several villi, before re-entering a larger vessel. The vessels of the villi (Fig. 221, *g*) are covered, as in

Fig. 221.†

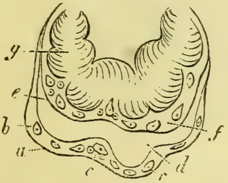
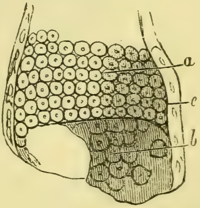


Fig. 222.‡



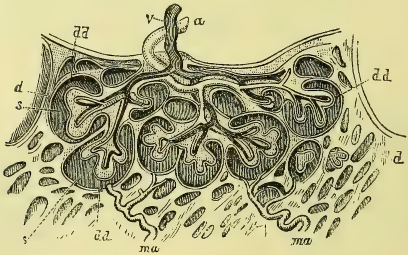
* Diagrammatic vertical section of Placenta, showing the fœtal tufts suspended in a cavity formed by an extension of the uterine sinuses:—*a*, *a*, chorion; *b*, *b*, decidua; *c*, *c*, orifices of uterine sinuses.

† Terminal loop of a Placental villus:—*a*, external membrane of the villus, continuous with the lining membrane of the vascular system of the mother; *b*, *c*, external cells of the villus, belonging to the placental decidua; *d*, the space between the maternal and fœtal portions of the villus; *e*, the internal membrane of the villus, continuous with the external membrane of the chorion; *f*, the internal cells of the villus, belonging to the chorion; *g*, the loop of umbilical vessels.

‡ Portion of the external membrane, with the external cells, of a Placenta villus:—*a*, cells seen through the membrane; *b*, cells seen from within the villus; *e*, cells seen in profile along the edge of the villus.

the chorion, by a layer of cells (f), enclosed in the basement membrane (e); but the *fœtal* tuft thus formed is enclosed in a second series of envelopes (a, b, c), derived from the *maternal* portion of the placenta; a space (d) being left between the two, however, at the extremity of the tuft. The maternal cells may be probably regarded as the first selectors of nutriment from the circulating fluid of the parent: the materials, partially prepared by them, are poured into the cavity surrounding the extremity of the tuft; and from this they are taken up by the fœtal cells, which impart them to the capillary loop (g) of the umbilical vessels. The vascular tufts not unfrequently extend beyond the uterine surface of the placenta, and dip-down into the uterine sinuses themselves, where they are bathed in the maternal blood.—The *maternal* portion of the placenta may be regarded as a large sac, formed by a prolongation of the internal coat of the great uterine vessels. Against the fœtal surface of this sac, the tufts just described may be said to push themselves, so as to dip-down into it, carrying before them a portion of its thin wall, which constitutes a sheath to each tuft. In this manner the whole interior of the placental cavity (Fig. 223) is intersected by numerous

Fig. 223.*



tufts of fœtal vessels, disposed in fringes, and bound down by the membrane that forms its proper wall; just as the intestines are covered and held in their places by the peritoneum. Now as this dilatation of the uterine blood-vessels carries the decidua before it, every one of the vascular tufts that dips-down into it will be covered with a layer of the cellular structure of the latter (Fig. 222); and this will also form a part of all the bands that connect

* Diagrammatic section of the Placenta, showing the relation of its Fœtal and Maternal portions:—*a*, branch of umbilical artery; *v*, branch of umbilical vein; *ma*, *ma*, maternal (curling) arteries, bringing blood into *s*, *s*, the maternal sinuses; *d*, their decidual lining; *d*, *d*, decidual covering of the fœtal tufts.

and tie-down the tufts. The blood is conveyed into the cavity of the placenta by the 'curling arteries,' so named from their peculiar course (Fig. 223, *ma*,), which proceed from the arteries of the uterus; and it is returned by large short straight trunks, which pass obliquely through the decidua, and discharge their contents into the great uterine sinuses (Fig. 220, *c*, *c*).

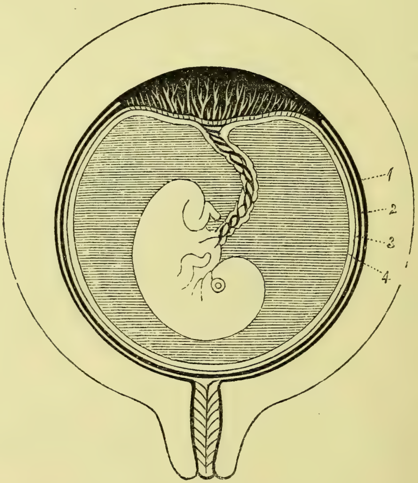
820. There is no more direct communication between the Mother and Fœtus than this; all the observations which have been supposed to prove a direct vascular continuity being certainly fallacious. The function of the Placenta is manifestly double. The fœtal tufts draw from the maternal blood the materials which are required for the nutrition of the embryo, these materials having been first selected and partially elaborated by the two sets of intervening cells; and in this character the fœtal tufts resemble the villi of the intestinal surface, which dip-down into the fluids of the alimentary canal, and absorb the nutritive material which they furnish. But the Placenta also serves as a respiratory organ, aërating the blood of the fœtus by exposing it to the influence of the oxygenated blood of the mother: and in this respect the fœtal tufts bear a close correspondence with the gills of aquatic animals, bringing the blood into relation with a surrounding fluid medium containing oxygen, which is imbibed by the blood in exchange for the carbonic acid given-off. And it is probable, too, that the Placenta is to be regarded as an excreting organ; serving for the removal, through the maternal blood, of excrementitious matters whose continued circulation in the blood of the fœtus would be prejudicial to it.

821. The formation of the Human Placenta commences in the latter part of the second month of utero-gestation; during the third, the organ acquires its proper character; and it subsequently goes-on increasing, in accordance with the growth of the ovum. The vessels of the Uterus undergo great enlargement throughout, but especially at the part to which the Placenta is attached; and the blood in moving through them produces a peculiar murmur, which is usually audible with distinctness at an early period of pregnancy, and which may be regarded (when due care is taken to avoid sources of fallacy) as one of its most unequivocal physical signs. The sound is most commonly heard near the situation of the Fallopian tube of the right side; and it corresponds with the pulse of the mother.

822. After the formation of the Placenta, no essential change takes place in the relations of the Embryo and its appendages to the Uterus; but the relative positions of certain parts are altered by differences in the rapidity of their rate of increase. Thus, in the earlier periods of fœtal life, the Amnion closely embraces the body of the fœtus, so that the cavity included between the two is very small; and the space between the amnion and the chorion

is then occupied by an amorphous gelatinous material, in whicl the umbilical vesicle lies imbedded (Fig. 214). Subsequently however, the amnion enlarges faster than the chorion, and th serous amniotic fluid which occupies its cavity increases in amount whilst the gelatinous layer intervening between the amnion an the chorion undergoes progressive absorption (Fig. 218), until at about the beginning of the fifth month, the external surface o the amnion comes into contact with the interior of the chorion During the later months of gestation the two membranes becom closely adherent to each other, and the quantity of amniotic flui goes on increasing, so that the fœtus has considerable range o movement within the cavity of the uterus (Fig. 224). The Um bilical Cord, which is formed in the first instance by the pedicle o

Fig 224.*



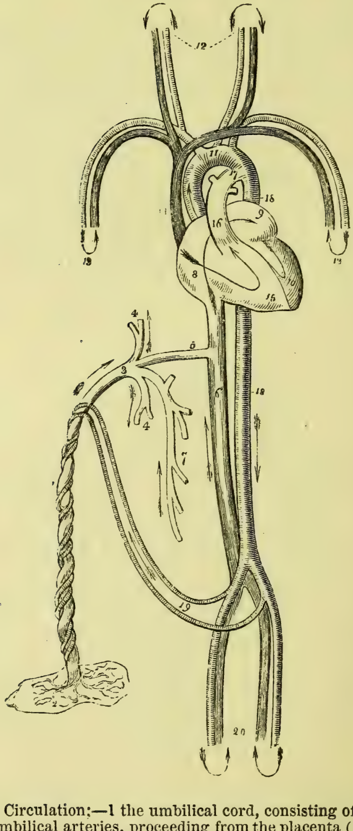
the allantois (Fig. 218), with the umbilical vessels running nearl straight along it, gradually elongates in proportion to the increasin size of the amniotic cavity; the portion of it formed by the allan

* Gravid Human Uterus with its contents, showing the relation of th cord, placenta, membranes, &c., at the end of the seventh month :—1, De cidua vera; 2, Decidua reflexa ; 3, Chorion ; 4, Amnion.

tois itself ceases to be distinguishable, the cord being essentially formed by the vessels deriving a tubular investment from the amnion, within which (although really on the outside of the amniotic sac, Fig. 224) there is a thick layer of the gelatinous substance intervening between the amnion and the chorion; and the cord becomes spirally twisted from right to left. The pedicle of the Umbilical vesicle may be distinguished during the earlier months of pregnancy; and the vesicle itself may be often traced by its guidance, as a small flattened shrivelled sacculus having a minute vessel distributed upon it.—The two layers of the Decidua, in the later months of pregnancy, are brought into close mutual contact by the increasing size of the ovum (Fig. 224, 1, 2); and at last they fuse together, so as to form only a single, thin, friable, semi-opaque layer, in which no trace of their original glandular structure can be discovered.—With the increase in the size of the ovum, a great augmentation takes place in the size of the Uterus, and also in the thickness of its walls; and this is mainly due to the development of an immense amount of new muscular tissue, which is of the unstriped kind (§ 332, Fig. 226).

823. It would be inconsistent with the character and objects of this Treatise, to follow in any detail the history of the development of the Fœtus during its intra-uterine life; and a general account of the evolution of most of the chief organs has been given in connection with that of their structure. The condition of the Circulating apparatus, however, at the period of birth, deserves especial notice. Up to that time the partition between the auricles is incomplete; a large aperture, the *foramen ovale*, still existing in it. There is also a direct communication between the pulmonary artery and the aorta, by the *ductus arteriosus:* and another direct channel between the umbilical vein and the vena cava, by the *ductus venosus*. The following is the course of the Blood. The fluid brought from the Placenta by the umbilical vein (Fig. 225, 3), is partly conveyed at once to the vena cava ascendens, by means of the ductus venosus (5), and partly flows through two trunks (4, 4), that unite with the portal vein (7) returning the blood from the intestines into the substance of the liver, thence to be conveyed to the vena cava by the hepatic vein. Having thus been transmitted through the two great depurating organs, the placenta and the liver, the blood that enters the vena cava is purely arterial in its character; but being mixed in the vessels with the venous blood that is returned from the trunk and lower extremities, it loses this character in some degree by the time that it reaches the heart. In the right auricle, which it then enters, it would also be mixed with the venous blood which is brought-down from the head and upper extremities by the descending cava; were it not that a very curious provision exists to impede (if it does not entirely prevent) any further admixture.

Fig. 225*.



* The Fœtal Circulation;—1 the umbilical cord, consisting of the umbilical vein and two umbilical arteries, proceeding from the placenta (2) ; 3, the umbilical vein dividing into three branches, two (4, 4) to be distributed to the liver, and one (5) the ductus venosus, which enters the inferior vena cava (6) ; 7, the portal vein, returning the blood from the intestines, and uniting with the right hepatic branch ; 8, the right auricle, the course of the blood being denoted by the arrow proceeding from 8 to 9, the left auricle ; 10, the left ventricle, the blood following the arrow to the arch of the aorta (11), to be

This consists in the arrangement of the Eustachian valve, which directs the *arterial* current (that flows upwards through the ascending cava) into the *left* side of the heart, through the foramen ovale, whilst it directs the *venous* current (that is being returned by the descending cava) into the *right* ventricle. When the ventricles contract, the arterial blood contained in the left is propelled into the *ascending* Aorta, and supplies the branches that proceed to the head and upper extremities, before it undergoes any further admixture: whilst the venous blood contained in the right ventricle is forced into the Pulmonary artery, and thence through the ductus arteriosus (17) which is like a continuation of its trunk, into the *descending* Aorta, mingling with the arterial current which that vessel previously conveyed, and thus supplying the trunk and lower extremities with a mixed fluid. A portion of this is conveyed by the umbilical arteries to the Placenta; in which it undergoes the renovating influence of the maternal blood, and from which it is returned in a state of purity.

824. Hence the head and superior extremities, whose development is required to be in advance of that of the lower, are supplied with blood nearly as pure as that which returns from the placenta; whilst the rest of the body receives a mixture of this with what has previously circulated through the system. The Pulmonary arteries convey little or no blood through the lungs; the current of blood propelled from the right ventricle, passing directly onwards through the ductus arteriosus into the aorta.—At birth, however, the course of the circulation undergoes great changes, that it may be adapted to the new mode in which the infant is henceforth to obtain its nutrition and to carry-on its respiration. As soon as the lungs are distended by the first inspiration, a portion of the blood of the pulmonary artery is diverted into them, and there undergoes aëration; and, as this proportion increases with the full activity of the lungs, the ductus arteriosus gradually shrinks, and its cavity finally becomes obliterated. At the same time, the foramen ovale is closed by a

distributed through the branches given-off by the arch to the head and upper extremities; the arrows 12 and 13, represent the return of the blood from the head and upper extremities through the jugular and subclavian veins, to the superior vena cava (14), to the right auricle (8), and in the course of the arrow through the right ventricle (15) to the pulmonary artery (16); 17, the ductus arteriosus, which appears to be a proper continuation of the pulmonary artery; the offsets at each side are the right and left pulmonary artery cut-off, which are of extremely small size as compared with the ductus arteriosus; the ductus arteriosus joins the descending aorta (18, 18), which divides into the common iliacs, and these into the internal iliacs, which become the hypogastric arteries (19), and return the blood along the umbilical cord to the placenta; while the other divisions, the external iliacs (20), are continued into the lower extremities, the arrows at the terminations of these vessels marking the return of the venous blood by the veins to the inferior cava.

valvular fold; and thus the direct communication between the two auricles is cut-off. When these changes have been accomplished, the circulation which was before carried-on upon the plan of that of the higher Reptiles (§ 563), becomes that of the complete warm-blooded animal; all the blood which has been returned in a venous state to the right side of the heart, being transmitted through the lungs before it can reach the left side, or be propelled from its arterial trunks.—It is by no means unfrequent, however, for some arrest of development to prevent the completion of these changes; and various malformations, involving an imperfect discharge of the circulating and respiratory functions, may hence result.

825. *Parturition.*— The average length of time which elapses between Conception and Parturition in the Human female, appears to be 280 days, or 40 weeks. There can be little doubt, however, that Gestation may be occasionally prolonged for one, two, or even three weeks, beyond that period; such prolongation not being at all unfrequent amongst the lower animals, and numerous well-authenticated instances of it in the Human female being upon record. Upon what conditions this departure from the usual rule is dependent, has not yet been ascertained; but it is a remarkable circumstance, ascertained by the observations of cattle-breeders, that the *male* has an influence upon the length of gestation, — a large proportion of cows in calf by certain bulls exceeding the usual period, and a small proportion falling short of it. In such cases, we must attribute the prolongation of the period to some peculiarity in the embryo, derived from its male parent.

826. The shortest period at which Gestation may terminate, consistently with the life of the child, has not been precisely ascertained; the difficulty of determining the exact date of conception being usually such, in this case as in the preceding, as to prevent the exact length of Gestation from being known. Thus, the commencement of pregnancy being fixed by the time of the cessation of the Catamenia, when there is no more definite guide, it is obvious that the act of Conception may have taken place during any part of the interval that has elapsed since the last monthly period; and thus a doubt may exist as to the length of the gestation, to the extent of from one to three weeks. There are very satisfactory cases on record, in which, from the degree of development at birth, as well as from other circumstances, the infant might be certainly known not to have attained 26 or 27 weeks, or little more than six months; and in which by careful treatment, it was reared in a condition of health and vigour. And there is reason to believe that infants have lived for some time, and might probably have been reared under better management, which were born as early as the 24th or 25th week.

827. The act of Parturition, by which the fœtus is expelled from the Uterus, is accomplished in part by the contractile power of the uterus itself, and in part by the combined operation of the various muscles which press upon the abdominal cavity, and which effect the expulsion of the fæces and urine. No definite account can be given of the reasons why this change should take place at the period which has been mentioned as its usual date; but we are as much in the dark in regard to other *periodic* phenomena of Animal life; and we must probably look for its source in the maturation of the placental structure, which prepares it for detachment (like the dropping-off of a ripe fruit), and in the complete evolution of the contractile tissue of the uterus, the contractions of which may be considered to commence spontaneously when it has attained a certain epoch in its growth, just as do those of the heart in the embryo (§ 816). For some days previously to the commencement of labour, there is usually a slow contraction of the fibres of the fundus and body of the uterus, and a yielding of those of the cervix; so that the child lies lower, and the size of the abdomen diminishes. This slow contraction is probably dependent, not upon any act of the nervous system, but upon the *direct* excitement of the contractility of the muscular substance of the uterus. When labour properly commences, however, the Spinal system of nerves comes into play, and the uterine contractions are of a reflex nature. As before, however, the act of contraction is confined to the fundus and body of the uterus; the fibres of the cervix uteri and of the vagina being in a state of relaxation, which allows them to yield to the pressure of the child's head. In the first stage of labour, the uterine contractions appear to be alone concerned; and it is not until the head of the child is passing through the os uteri and is entering the vagina, that the assistance of the abdominal muscles is called-in. These act, in the first instance, as in ordinary expiration; but their power is much increased by the voluntary retention of the breath, so that the whole of their contractile force may be applied to the expulsion of the fœtus. In a later stage of labour, this retention of the breath becomes involuntary, during the accession of the 'pains;' and the expulsion of the fœtus is commonly effected with considerable force, especially if the previous resistance has been excessive.

828. The same action which expels the fœtus, usually detaches the placenta; and if the uterus contract with sufficient force after this has been thrown-off, the orifices of the vessels which communicated with it are so effectually closed, that little or no hemorrhage from that source takes-place. When efficient contractions do not occur, they may frequently be excited by pressure upon the uterus itself, by the application of cold to the abdominal surface, to the extremities, and (in severe hemorrhage) to the

entire body, or by the application of the child to the nipple, which will frequently at once succeed in producing the desired effect. The efficacy of these means,—the latter in particular,—obviously depends upon the influence of the Spinal Cord and its nerves upon the muscular fibres of the uterus; the application of cold to the surface, or the irritation of the nipple, occasioning a reflex action in the uterus. But it is probable that this organ has also considerable power of contracting, independently of the nervous system; thus there are well-authenticated cases on record, in which the fœtus has been expelled after the *somatic* death (§ 64) of the parent: this must have been in consequence of the persistence of the independent contractility of the uterus, and the relaxed state of all the parts through which the child had to make its exit.

829. The cause of the occasional occurrence of the parturient effort at an unusally-early period, is as little understood as that of their ordinary action. There are some individuals in whom this regularly happens at a certain month, so that it seems to be an action natural to them. In many cases, however, it may be traced to some undue exertion of body, or mental excitement; and not unfrequently to a general constitutional irritability, which renders the system liable to be deranged by very trifling causes. Premature labour is always to be prevented, if possible, being injurious alike to both mother and child; and for this prevention we have chiefly to rely upon rest and tranquillity of mind and body, and upon the careful avoidance of all those exciting causes which are liable to produce uterine contractions by their operation upon the nervous system; whilst, at the same time, any measures which will invigorate the body, without stimulating it, should not be overlooked.

830. The Uterus, in the act of parturition, not only empties itself of the entire mass of the Fœtus and its membranous envelopes forming the ovum, and of the whole substance of the Placenta, but also throws off the entire Decidua, the greater part of which has previously fallen into a state of atrophy, and has very little vascular connection with the Uterus. Underneath this portion there is already a preparation for the formation of a new mucous membrane; but as that portion which intervened between the placenta and uterine surface is extremely vascular, its detachment cannot be accomplished without hemorrhage; and after it has been thrown off, the muscular substance of the uterus is left completely exposed. After the lapse of two months, however, the mucous lining of the uterus is everywhere completely regenerated.—Almost immediately after parturition, the muscular substance of the Uterus begins to undergo a rapid 'fatty degeneration;' and its component fibres are absorbed and disappear, their place being subsequently in part taken by other

fibres of new formation (Fig. 226). In this manner the uterus is brought down to its original size, and its muscular substance is completely renovated; this process also seems to be usually completed

Fig. 226.*

within two months after delivery. The Lochial discharge probably carries off a considerable amount of the products of degeneration; but a large quantity of oil-globules have been observed in the Urine of women recently delivered; and it seems not unlikely that some of the fatty matter may pass into the Milk, which is particularly rich in that substance during the earlier months of lactation (§ 835).

831. *Lactation.*—A peculiar preparation is made, in the females of the class Mammalia, for the sustenance of the infant during a long period after birth. This consists in the secretion of a fluid, from the glands termed *Mammary*, which contains all the elements required for the development of the body of the infant during the first year. These glands present themselves in an almost rudimentary state in some of the non-placental animals of the class; consisting only of a few large follicles, which open separately upon the surface (Fig. 160). In the higher Mammalia, however, we find it composed of vast numbers of minute follicles, clustered together upon excretory ducts. The general arrangement of these in the Human subject is seen in Fig. 227; and the character of the follicles themselves, and of the secreting epithelial cells they contain, as seen under a much higher magnifying

* Muscular fibres of unimpregnated Uterus.

power, has been already shown in Fig. 43. Each Mammary gland consists of a number of glandulæ, which are held together by connective tissue; this arrangement may probably have reference to the mobility which it is requisite that the different parts of the mass should possess, one upon the other, in consequence of its situation upon the pectoralis muscle. The ducts converge and unite together, so as at last to form ten or twelve principal trunks, which terminate in the nipple. At the base of the nipple these tubes dilate into reservoirs, which extend beneath the areola, and to some distance into the gland, when the breast is in a state of lactation. These, which are much larger in many of the lower Mammalia than they are in the Human female, seem to have for their office to contain a store of milk, sufficient to supply the immediate wants of the child when it is first applied to the breast; so that it shall not be disappointed, but shall be induced to proceed with sucking until the *draught* be occasioned (§ 836).—The Mammary gland may be detected at an early period of fœtal existence, then presenting no difference in the male and female; and it continues to grow, in each sex, in proportion to the body at large, up to the period of puberty. At that epoch, however, the gland begins to undergo a special enlargement in the female; and by the age of twenty, it attains its full size previous to lactation. Even then, however, the milk-follicles cannot be injected from the tubes. During pregnancy, the mammary glands receive a greatly-increased quantity of blood. This determination often commences very early; and produces a feeling of tenderness and distention, which is a valuable sign (where it occurs in conjunction with others) of conception having taken place. The vascularity of the gland continues to increase during pregnancy; and at the time of parturition its lobulated character can be distinctly felt. The follicles cannot be readily injected, however, until the gland is in a state of complete functional activity; *i.e.*, during lactation.—The Mammary gland of the Male does not undergo this increase of development, except under certain peculiar circumstances to be presently noticed (§ 836); and it remains a sort of miniature picture of that of the female, its diameter varying from that of a large pea to an inch or even two inches.

Fig. 227.*

832. The Milk, secreted by the Mammary glands, consists of

* Termination of portion of Milk-duct in follicles, from a mercurial injection by Sir A. Cooper.

Water, holding in solution the peculiar Albuminous substance termed Casein, and various Saline ingredients, together with (in most cases) a certain form of Sugar; and having Oleaginous globules suspended in it. These globules are surrounded by a thin albuminous pellicle, which keeps them asunder so long as the milk remains at rest.—The existence of these elements in ordinary Milk (as that of the Cow) is made apparent by the processes to which it is subjected in domestic economy. If it be allowed to stand for some time, exposed to the air, a large part of the oleaginous globules come to the surface in consequence of their inferior specific gravity; and thus is formed the *cream*, which includes also a considerable amount of casein, with the sugar and salts of the milk. These may be partly separated by the continued agitation of the cream, as in the process of 'churning;' this, by rupturing the envelopes of the oil-globules, separates it into *butter*, which is formed by their aggregation, and *butter-milk*, containing the casein, sugar, &c. A considerable quantity of casein, however, is still entangled with the oleaginous matter; and this has a tendency to decompose, so as to render the butter rancid. It may be separated by keeping the butter melted at a temperature of 180°, when the casein will fall to the bottom, leaving the butter pure and much less liable to change; an operation which is commonly known as the *clarifying* of butter.—The Milk, after the cream has been removed, still contains the greater part of its casein and sugar. If it be kept long enough, a spontaneous change takes-place in its composition; an incipient decomposition in the casein being the cause of the conversion of the sugar into lactic acid, and this coagulating the casein by precipitating it in small flakes. The same precipitation may be accomplished at any time by the agency of various acids, especially the acetic, which does not act upon albumen; but casein cannot be coagulated, like albumen, by the influence of heat alone (§ 183). The most complete coagulation of casein is effected by the agency of the dried stomach of the calf, known as *rennet;* which exerts so powerful an influence as to coagulate the casein of 1800 times its weight of milk. It is thus that, as in the making of cheese, the *curd* is separated from the *whey;* the former consisting chiefly of the casein, whilst the latter contains a large proportion of the saline and saccharine matter which entered into the original composition of the milk. These may be readily separated by evaporation.

833. The principal characters of *Casein* have been already stated (§ 183). That of Human milk is much less readily precipitable, either by acids or by rennet, than is that of the milk of the domesticated Mammals generally; the casein of Ass's milk being that which approaches it most nearly in this respect.—The *Oleaginous* matter chiefly consists, like the fats in general, of

stearine or margarine with oleine (§ 176); but it also contains another substance peculiar to it, which is termed *butyrine*. This last (to which the characteristic smell and taste of butter are due) is converted by saponification into three volatile acids, of strong animal odour, to which the names of butyric, capric, and caproic acids have been given. This change may be effected at any period by treating the butyrine with alkalies; but it may also take-place by spontaneous decomposition, which is favoured by time and moderate warmth.—The *Sugar* of Milk, which is closely related in composition and properties to Glucose (§ 175), is chiefly remarkable for its proneness to conversion into lactic acid, under the influence of a *ferment* or decomposing azotized substance.—The *Saline* matters contained in Milk appear to be nearly identical with those of the blood; with a larger proportion, however, of the phosphates of lime and magnesia, which amount to 2 or $2\frac{1}{2}$ parts in 1000. These are held in solution chiefly by the casein, which has a remarkable power of combining with them.

834. Thus ordinary Milk contains the three classes of Organic principles which form the chief part of the food of animals,—namely, the Albuminous, the Saccharine, and the Oleaginous; together with the Mineral elements which are required for the development and consolidation of the fabric of the infant. It would appear, however, that the combination of all these is not necessary, but that it rather has reference to the composition of the food on which the animal is destined to be afterwards supported. Thus in Carnivora exclusively fed on flesh, the milk contains little or no sugar, which principle is altogether wanting in the food of the adult; but the milk of a bitch fed partly on amylaceous substances contains sugar. Amongst the different species of Herbivorous animals, the proportion of the several ingredients varies considerably; and it is also liable to considerable variation in accordance with the nature of the food, the amount of exercise taken by the animal yielding the milk, and other circumstances. Thus, in the milk of the Cow, Goat, and Sheep, the average proportions of casein, butter, and sugar are nearly the same one with another (casein predominating, however, in the milk of the Cow), each amounting to from 3 to 5 per cent. In the milk of the Ass and Mare, on the other hand, the proportion of casein is under 2 per cent., the oleaginous constituents are scarcely 1 per cent., whilst the sugar and allied substances rise to 7 or 8 per cent. In the Human female, the saccharine and oleaginous elements predominate, the amount of casein being intermediate between that of Ass's and that of Cow's milk.—The proportion of the saccharine and oleaginous elements in any kind of milk appears to be considerably affected by the amount in which these are present in the food, and by the degree in which the quantity ingested is consumed by the respiratory process. Thus a low

external temperature and out-door exercise, by increasing the production of carbonic acid from the lungs, cause a consumption of the oleaginous and saccharine matters which might otherwise pass into the milk, and thus diminish the amount of cream. On the other hand, exercise favours the secretion of casein; which would seem to show that this ingredient is derived from the disintegration of the azotised tissues. Thus, in Switzerland, the cattle which pasture in exposed situations, and which are obliged to use a great deal of muscular exertion, yield a very small quantity of butter, but an unusually-large proportion of cheese; yet the same cattle, when stall-fed, give a large quantity of butter and very little cheese.

835. The Milk first secreted after parturition, known as the *Colostrum*, is very different from ordinary milk; and possesses a strongly purgative action, which is useful in clearing the bowels of the infant from the various secretions which have accumulated in them at birth, constituting the *meconium*. The Colostrum, when examined with the Microscope, is found to contain a multitude of large yellow granulated corpuscles, each of which seems composed of a number of small grains aggregated together; these corpuscles are probably metamorphosed epithelial cells of the mammary ducts. The Colostric character is sometimes retained for some time after birth, and severely affects the health of the infant. This may happen without any peculiarity in the ordinary characters of the secretion, which has all the appearance of healthy milk; but the Microscope at once detects the difference by the presence of the colostric corpuscles.—The proportion of Fat is much greater in the early months of lactation; whilst that of Casein increases with the age of the infant.

836. The formation of this Secretion is influenced by the Nervous system to a greater degree, perhaps, than that of any other. The process may go-on continuously, to a slight degree, during the whole period of lactation; but it is only in animals which have special reservoirs for the purpose, that any accumulation of the fluid can take-place. In the Human female, as we have seen, these are so minute as to hold but a trifling quantity of milk; and the greater part of the secretion is actually formed whilst the child is at the breast. The irritation of the nipple produced by the act of suction, and the mental emotion connected with it, concur to produce an increased flow of blood into the gland, which is known to nurses as the *draught;* and thus the secretion is for the time greatly augmented. The 'draught' may be produced simply by an emotional state of the mind, as by the thought of the child when absent; whilst the irritation of the nipple may alone occasion it; but the two influences usually act simultaneously.—The most remarkable examples of the influence of such stimuli on the Mammary secre-

CHAPTER XIII.

OF THE NERVOUS SYSTEM AND ITS ACTIONS

1. *General View of the Operations of which the Nervous System is the instrument.*

840. We have now considered the entire series of those operations which make-up the *Vegetative* or *Organic* life of the Animal; including those functions by which the germ is prepared, by which it is nourished until it can be left to its own powers, by which its continued development is effected until the fabric characteristic of the adult has been built-up, and by which the normal constitution is maintained through a lengthened period,—so long as the necessary materials are supplied, and no check or hindrance is interposed by external influences to that regular sequence of changes on which the continuance of its powers depends. In this survey it will have been perceived that the *essential* parts of these operations are, in Animals as in Plants, completely independent of the influence of that which constitutes the peculiar endowment of Animals,—namely, the Nervous System.

a. The *Reduction* of the food in the Stomach, by the solvent power of the gastric fluid, is a purely chemical operation, with which the Nervous System has nothing whatever to do, excepting in so far as it promotes the secretion of the solvent, and stimulates the Muscular coat of the stomach to that peculiar series of contractions, which keeps the contents of the cavity in continual movement, and thus favours the action of the solvent upon them.

b. In the process of *Absorption*, by which the nutritive materials with other substances are introduced into the vessels, the Nervous System has no participation; this being a purely-vegetative operation, partly dependent upon the simple physical conditions which produce Osmosis, and partly on a process of cell-selection.

c. The *Assimilation* of the new material, effected, as we have seen reason to believe, by another set of independent cells, can receive but little influence from the Nervous System, and is obviously capable of taking-place without its aid.

d. The *Circulation* of the Blood, again, though dependent in part upon the impulsive power of a Muscular organ, the Heart, is not on that account brought into closer dependence upon the Nervous System; for we have seen that the contractions of the heart result from its own inherent powers, commencing in the embryo before the nervous centres have been developed, and continuing after the complete detachment of the organ from the body; whilst the *capillary power*, which is the chief agent in the movement of the blood in the lower animals, and which exerts an

important subsidiary action in the higher, is the result of the exercise of certain affinities between the blood and the surrounding tissues, in which the Nervous System can have no immediate concern.

e. The act of *Nutrition*, in which every tissue draws from the circulating blood the materials for its own continued growth and development, and by which it incorporates these with its own substance, essentially consists in a continuance of the same kind of operation as that which takes-place in the early development of the embryo, long anteriorly to the first appearance of the Nervous System,—namely, a process of cell-development and metamorphosis, which must be, from its very nature, independent of Nervous agency, though capable of being influenced by it.

f. The same may be said of the *Secreting* operation in general; for this essentially consists in the separation of certain products from the blood, by cells situated upon free surfaces, which thus remove those products from the interior of the fabric.

g. And the interchange of oxygen and carbonic acid, which takes place between the atmosphere and the venous blood when brought into mutual relation in the lungs, and which is the essential part of the function of *Respiration*, is an operation of a merely physical character, with which the Nervous system can have no direct concern.

h. Finally, the development of the 'sperm-cells' in the one sex, and of the ova containing 'germ-cells' in the other, the subsequent fertilization of the latter by the former, and the changes consequent upon that act, together making-up the function of *Generation*, may be all regarded as modifications of the ordinary Nutritive processes; and are effected, like these, by the inherent powers of the parts concerned in them, at the expense of the materials supplied by the blood, without any direct dependence upon the Nervous system.

841. Still, although the various processes which make-up the *essential* part of the nutritive operations, in Animals as in Plants, are no more dependent on any peculiar influence derived from a Nervous system in the former, than they are in the latter, it must be evident from the details already given, that there must be in Animals various *accessory* changes, which are requisite for the continuance of those processes, and which can only be effected by the peculiar powers with which Animals are endowed.—Thus, to commence with Digestion; this preliminary operation, which the nature of the food of the Plant renders unnecessary for *its* maintenance, can only be accomplished by the introduction of the food into a cavity or sac, in which it may be submitted to the action of the solvent fluid. The operation of *grasping* and *swallowing* the food, in the higher Animals at least, is accomplished through the agency of the Nervous system; and if it be checked

by the loss of Nervous power, the Digestive process must ceas for want of material.—So, again, although the interchange o gaseous ingredients between the atmosphere and the circulatin fluid, may take-place with sufficient energy in Plants and th lower animals through the mere exposure of their general surfac to the atmosphere, yet we find that in all the higher Animal certain movements are requisite, for the continual renewal of th air or the water which is in contact with one side of the respirator surface, and of the blood which is in relation with the other: an for the maintenance of these Respiratory movements, a Nervou system is requisite.—In the Excretory processes, moreover, th removal of the effete matters from the body can only be accomplished, in the higher Animals, by certain combined movements the object of which is to take-up the products that are separate by the action of the proper secreting cells, and to carry them to the exterior of the body, there to be set-free: and these combined movements can only be effected by the agency of the Nervous system.—Lastly, in the act of Reproduction, the arrangement of the sexual organs in Animals requires that a certain set of movements should be adapted to bring together the contents of the 'sperm-cells' of the male, and of the 'germ-cells' of the female; and also for the expulsion of the ovum from the body of the latter, in a state of more or less advanced development: for these movements a special arrangement is made in the construction of the Nervous system, and in the application of its peculiar powers.

842. Thus we see that although the Organic functions of the Animal are essentially independent of the Nervous System, this system affords the conditions which are requisite for their continued maintenance; being the instrument whereby the muscles are called into action for the performance of those various combined actions, that constitute the *mechanism* (so to speak) by which the Vegetative part of the fabric is combined with the Animal portion of the organism. We are not to suppose, however, that *every* movement which takes-place in the Animal body is dependent upon the Nervous System; for we have seen that the Muscular tissue may be employed to perform contractions excited by stimuli applied to itself, and that it may thus execute a set of movements in which the nervous system has no direct participation. And it is desirable that the Student should observe, that these are, in all instances, those most *directly* connected with the Vegetative functions, and, at the same time, those of the simplest and most straightforward character.—Thus, the peristaltic movement by which the alimentary and fæcal matters are propelled along the Intestinal tube, results from the *direct* excitement of the contractility of its muscular walls, and is entirely independent of Nervous agency; and this movement is accomplished by the successive contractions of the different fasciculi surrounding the tube, which take-up (as

it were) each other's action (§ 346). So, again, the successive contractions and dilatations of the cavities of the Heart, which perform so important a part in the Circulation of the blood, are the result of the properties inherent in that organ; the muscular fibres of which are excited to a peculiar rhythmical and consentaneous contraction, by the flow of blood into the cavities when dilating. Moreover, in the Excretory ducts of various glands we find a muscular coat, by which the fluids secreted in the Glands are propelled towards their outlet on the exterior of the body or on one of its free internal surfaces.

843. In these instances, then, we observe that the simple Contractility of Muscular structure, excited by *direct* stimulation, is applied to effect the movements most closely connected with the Organic functions. The processes, therefore, which take place in the *penetralia* of the organism are essentially independent of the Nervous System; though it undoubtedly possesses a certain control over them, the action of the Heart in particular being modified through its agency. But it is one important office of the Nervous System to guard the *portals* for entrance and exit, to fill those chambers which admit the new materials from the external world, or to empty the receptacles which collect from the interior of the system the effete matters that are to be cast-out from it. And we find that for these offices it is employed in its very simplest mode of operation;—that which does not involve Sensation, Intelligence, Will, or even Instinct (in the proper sense of that term), but which may take place independently of all consciousness,—by the simple *reflexion* of an impression, conveyed *to* a ganglionic centre by one set of fibres proceeding towards it from the circumference, along another set which passes *from* it to the muscles and calls them into operation (§ 393). This 'reflex function,' therefore, is the simplest application of the Nervous System in the Animal body. We shall presently see reason to believe that a very large proportion of the movements of many of the lower animals are of this reflex character; and that they are not necessarily accompanied by sensation, although this may usually be aroused by the same cause which produces them. As we rise, however, in the scale of Animal existence, we find the reflex movements forming a smaller and smaller proportion of the whole; until, in Man, they constitute so limited a part of the entire series of movements of which the Nervous system is the agent, that their very existence has been overlooked.

844. But the main purpose of the Nervous System is to serve as the instrument of those *Psychical** powers, which are the distinguishing attribute of the Animal. It has been already pointed

* This term, derived from the Greek ψυχη, is used to designate the sensorial and mental endowments of Animals, in the most comprehensive acceptation of those terms.

out, that the possession of *consciousness* (or of the capability of receiving sensations), and the power of executing *spontaneous* movements (that is, movements which are not immediately dependent upon external stimuli), constitute the essential features in which the Animal differs from the Plant. All the other differences in structure that respectively characterize these two classes of living beings, are subordinate to this one leading distinction,—the presence of a Nervous System and of its peculiar attributes in the one,—and its absence in the other. Now when we attempt to analyze these peculiar attributes, we may resolve them, like the properties of the material body, into different groups. We find that the *first* excitement of all mental changes, whether these involve the action of the *feelings* or of the *reason*, depends upon *sensations;* which are produced by impressions made upon the nerves of certain parts of the body, and are conveyed by these to a particular ganglionic centre, which is termed the *Sensorium*,—being the part with which Sensation, or the capability of *feeling* external impressions, is especially connected.

845. Now there are numerous actions, especially among the lower Animals, which seem to be as far removed from the influence of the Will, and as little directed by Intelligence, as the 'reflex' movements themselves; but which, nevertheless, depend upon sensation for their excitement. The sensation may *immediately* direct the movement, and may call the muscular apparatus into action in such a manner, as—without any calculation of consequences, any intentional adaptation of means to ends, any exertion of the reason, or any employment of a discriminating Will—to produce an action, or train of actions, as directly and obviously adapted to the well-being of the individual, as we have seen those of the reflex character to be. Of this an excellent example is afforded in our own system by the act of Sneezing; the purpose of which is obviously to expel from the nasal passages those irritating matters, the sense of whose presence excites the complicated assemblage of muscular movements concerned in the operation. This class of actions may be appropriately termed *Sensori-motor* or *Consensual;* and under it we may include most of those purely *instinctive* actions of the lower animals, which, being prompted by sensations, cannot be assigned to the reflex group. These seem to make-up, with the reflex, nearly the whole of the Animal functions in many tribes (§ 860); but they are found to be gradually brought under the domination of the Intelligence and Will as we rise towards Man, in whom those faculties are most strongly developed, so as to keep the Consensual as well as the Reflex actions quite in subordination to the more elevated purposes of his existence.—Closely allied, however, to these, are the purely *Emotional* movements; in which the sensation excites a mental feeling or impulse, that reacts upon the muscular system without

giving rise to any distinct *idea*, and consequently without having called the intellect and will into exercise. In fact, these Emotional movements are often performed in opposition to the strongest efforts of the Will to restrain them ; as when laughter is provoked by some ludicrous sight or sound, or by the remembrance of such, at an unseasonable time. It is probable, from the strong manifestations of emotion exhibited by many of the lower animals, that some of the actions which we assemble under the general designation of 'instinctive,' are to be referred to this group.

846. There are many sensations, however, which do not thus immediately give-rise to muscular movements; their operation being rather that of stimulating to action the Intellectual powers. It can scarcely be doubted that *all* Mental processes are dependent in the first instance upon Sensations, which serve to the Mind the same kind of purpose that food and air fulfil in the economy of the body. If we could imagine a being to come into the world with its mental faculties fully prepared for action, but destitute of any power of receiving sensations, these faculties would never be aroused from the condition in which they are in profound sleep; and such a being must remain in a state of complete unconsciousness, because there is nothing of which it can be made conscious, no *feeling* or *idea* which can be aroused within it. But after the mind has once been in active operation, the destruction of all *future* power of receiving sensations would not reduce it again to the inactive condition. For the ideas produced by former sensations are so stored-up in the mind by the power of Memory, that they may give-rise to mental processes at any future time; and thus the mind may feed (as it were) upon the *past*. Now the ideas which are excited by sensations, and which are coloured by the state of feeling which accompanies them, become the subjects of Reasoning processes more or less complex, sometimes of the utmost brevity and simplicity, sometimes of the most refined and intricate nature. These reasoning processes may result in an impulse to perform a particular action, which, in so far as it is the expression of a definite *purpose* or *designed* adaptation of means to ends on the part of the performer, instead of being the result of a mere blind indiscriminating impulse, is to be accounted an act of *Intelligence*. In the execution of such a purpose, however, the Will is not necessarily called into action; for *ideas*, like sensations, may automatically call forth movements, as we see them do in the states of Reverie, Somnambulism, &c., in which the Will is temporarily in abeyance. Such movements may be appropriately designated *Ideo-motor*. It is probable that those intelligent actions which many of the lower animals (the Dog, Horse, Elephant, &c.) are undoubtedly capable of performing, are to be referred to this category; since we have no reason to believe that any such beings possess that power of directing and controlling

the current of thought and feeling, which gives to the Will of Man the power of keeping in check the automatic impulses of his mind as well as those of his body, or of utilizing them to its own purposes.—The *Volitional* movements, which are the direct results of the exertion of the Will, constitute the highest form of the action of the Nervous System; since these are the expressions of a power which is beyond and above all that can be accounted a mere automatic mechanism, responding in fixed and determinate modes to external impressions.

847. Thus, then, we have to consider the Nervous system under five heads;—*first*, as the instrument of the Reflex actions;—*second*, as the instrument of the Consensual actions;—*third*, as the instrument of the Emotional actions;—*fourth*, as the instrument of the Intellectual processes, which may express themselves in Ideo-motor actions;—and *fifth*, as the instrument of Volitional movements. There is reason to believe that the Nervous Centre from which the muscles immediately derive their impulse to contract, is the same, whether the movement be prompted by an *impression* which does not excite the consciousness, by a *sensation*, by an *emotion*, by an *idea*, or by a *volition;* and that this instrument may be played-upon (so to speak) by other centres, which minister to these functions respectively.—In order that the relations of the component parts of the Nervous apparatus may be better understood, it will be desirable to take a brief survey of its comparative structure in the principal groups of Animals; and to inquire what actions may be justly attributed to its several divisions in each instance: commencing with those in which the structure is the simplest, and the variety of actions the smallest; and passing-on gradually to those in which the structure is increased in complexity by the addition of new and distinct parts, and in which the actions present a corresponding diversity.

2. *Comparative Structure and Actions of the Nervous System.*

848. From what has been already said (§§ 371-80) of the characters of the two elementary forms of the Nervous Tissue, it is evident that no Nervous System can exist in which both these forms should not be present. We look, therefore, for *ganglia* composed of the *vesicular* nervous substance, and serving as the centres of nervous power; and for cords or *trunks* composed of the *tubular* substance, and serving to communicate between the ganglia and the parts with which they are to be functionally connected. Now it is quite certain that, at present, no such Nervous apparatus can be detected in many of the lowest Animals; and some Physiologists have had recourse to the supposition of their possessing a 'diffused' nervous system,—that is, of their possessing nervous particles in a separate form, incorporated

(as it were) with their tissues. The fact appears to be rather, that the whole of the sarcodic substance of which the soft parts of their bodies are composed (Fig. 198), is endowed in a low degree with that power of receiving, conducting, and reacting upon external impressions, which, raised to a much more exalted degree, is the special attribute of Nervous substance, and which may be designated *Neurility;* just as it is endowed with a low degree of that contractility, which, raised to a higher degree, is the special attribute of Muscular fibre. In each case, we find that with the development of these special tissues, the general substance of the body loses the endowments respectively characteristic of them; and wherever we find a definite Muscular apparatus and Sensory Organs, there is a strong presumption that there must also be a definite Nervous system, whose action may be purely *internuncial,* that of calling forth Muscular movements in respondence to the impressions made by external agencies. The apparent absence of a Nervous system is doubtless to be attributed in many instances to the general softness of the tissues of the body, which prevents it from being clearly made-out among them. And it is to be remembered, that, on the principles already stated, we should expect to find it bearing a much smaller proportion to the entire structure, in these lowest Animals whose functions are chiefly Vegetative, than in the highest, in which the vegetative functions seem destined merely for the development and subsequent maintenance of the Nervous and Muscular systems.

849. Among the *Radiated* classes, the parts of whose bodies are arranged in a circular manner around the mouth, and repeat each other more or less precisely, the Nervous system presents a corresponding disposition. In the Star-fish, for example, which is one of the highest of these animals, it forms a ring which surrounds the mouth; this ring consists of nervous cords, which form communications between the several ganglia, one of which is placed at the base of each ray. The number of these ganglia corresponds with that of the rays or arms; being *five* in the common Star-fish; and from *nine* to *fifteen* in the species possessing those several numbers of members. The ganglia appear to be all similiar to each other in function, as they are in the distribution of their branches; every one of them sending a large trunk along its own ray, and two small filaments to the organs in the central disk. The rays being all so similar in structure as to be exact repetitions of each other, it would appear that none of the ganglia can have any controlling power over the rest. All the rays (in certain species) have at their extremities what seem to be very imperfect eyes; and so far as these can aid in directing the movements of the animal, it is obvious that they will do so towards all sides alike. Hence there is no one part which corresponds to the *head* of higher animals; and the ganglia of the

nervous system, like the parts they supply, are but repetitions o one another, and are capable of acting quite independently Each would perform its own individual functions if separate from the rest; but in the entire animal their actions are all con nected with each other by the circular cord, which passes fron every one of the ganglia to those on either side of it. W shall find that, in Articulated and Vertebrated animals, there is similar repetition of corresponding ganglia on the two sides of th median plane of the body; and that these are connected b *transverse* bands, analogous in function to the circular cord o the Star-fish. Moreover, we shall see a like repetition of ganglia almost or precisely similar in function, in passsng from one extre mity of these animals to the other; and these ganglia are con nected by longitudinal cords, whose function is in like manne *commissural.*— From the best judgment we can form of th actions of the Star-fish, by comparing them with the correspondin actions of higher animals, we may fairly regard the greate number of them as simply *reflex;* being performed in direct respondence to external stimuli, the impression made by which i propagated to one or more of the ganglia, and excites in them a motor impulse. How far the movements of these animals are indicative of *sensation,* we have not the power of determining; but it may be safely affirmed that they afford no indication of the exercise either of reasoning faculties or of voluntary power.

850. Perhaps the simplest form of a Nervous system is that presented by certain of the lower *Mollusca*; for the body not here possessing any repetition of similar parts, the nervous system is destitute of that multiplication of ganglia which we see in the Star-fish; whilst the limited nature of the animal powers involves a corresponding simplicity in the integral parts of their instrument. The Animals to which reference is here made, form the class *Tunicata*, which is intermediate in many respects between the ordinary Mollusks and the Zoophytes. They consist essentially of an external membranous bag or tunic, within which is a muscular envelope, and again within this a respiratory sac, which may be considered as the dilated pharynx of the animal (Fig. 144). At the bottom of this last is the entrance to the stomach, which, with the other viscera, lies at the lower end of the muscular sac. The external envelopes have two orifices; a mouth to admit water into the pharyngeal sac; and an anal orifice for the expulsion of the water which has served for respiration, and of that which has passed through the alimentary canal, together with the fæcal matter, the ova, &c. A current of water is continually being drawn into the pharyngeal sac by the action of the cilia that line it; and of this a part is driven into the stomach, conveying to it the necessary supply of aliment in a very finely divided state; whilst a part is destined merely for the aëration of

the circulating fluid, and is transmitted more directly to the anal orifice after having served that purpose. These animals are for the most part fixed to one spot, during all save the earliest period of their existence; and they give but little external manifestation of life, beyond the continual entrance and exit of the currents already adverted-to, which, being effected by ciliary action, are altogether independent of the nervous system (§ 241). When any substance is drawn-in by the current, however, the entrance of which would be injurious, it excites a general contraction of the mantle or muscular envelope; and this causes a jet of water to issue from one or both orifices, which carries the offending body to a distance. And in the same manner, if the exterior of the body be touched, the mantle suddenly and violently contracts, and expels the contents of the sac.

851. These are the only actions, so far as we know, which the Nervous system of these animals is destined to perform. They scarcely exhibit a trace of eyes, or of other organs of special sense; and the only parts that appear peculiarly sensitive, are the small 'tentacula' or feelers that guard the oral orifice. Between the two apertures in the mantle we find a solitary ganglion, which receives branches from both orifices, and sends others over the muscular sac. This, so far as we know at present, constitutes the whole nervous system of the animal; and it is fully sufficient to account for the movements which have been described. For the impression produced by the contact of any hard substance with the tentacula, or with the general surface of the mantle, being conveyed by the *afferent* fibres to this ganglion, will excite in it a reflex motor impulse; which, being transmitted to the muscular fibres of the contractile sac, as well as to those circular bands that surround the orifices and act as *sphincters*, will call-forth the movements in question.

852. In the *Conchifera*, or Mollusks inhabiting 'bivalve' shells, there are always at least two ganglia having different functions. The larger of these (Plate II., Fig. 1, *c*), corresponding to the single ganglion of the Tunicata, is situated towards the posterior end of the body (that is, the end most distant from the mouth), in the neighbourhood of the posterior muscle that draws the valves together; and its branches are distributed to that muscle, to the mantle, to the gills (*d*, *d*), and to the siphons (*e*, *e*) by which the water is introduced and carried off. But we find another ganglion, or rather pair of ganglia (*a*, *a*), situated near the front of the body, either upon the œsophagus, or at its sides; these ganglia are connected with the very sensitive tentacula which guard the mouth; and they may be regarded as presenting the first approach, both in position and functions, to the brain of higher animals. In the *Oyster* and others of the lower Conchifera which have no foot, these are the

only principal ganglia; but in those having a foot, which is a muscular tongue-like organ, we find an additional ganglion (*b*) connected with it. This is the case in the *Solen* or animal of the 'razor-shell;' whose foot is a very powerful boring-instrument, enabling it to penetrate deeply into the sand.—Here, then, we have three distinct kinds of ganglionic centres; every one of which may be doubled, or repeated on the two sides of the body. *First*, the *cephalic* ganglia (*a*, *a*), which are probably the sole instruments of *sensation* and of the *consensual* movements; these are almost invariably double, being connected together by a transverse band, which arches over the œsophagus. *Second*, the *pedal* ganglion (*b*), which is usually single, in conformity with the single character of the organ it supplies; but in one very rare Bivalve Mollusk, the foot being double, the pedal ganglion is double also. *Third*, the *respiratory* ganglion (*c*), which frequently presents a form that indicates a partial division into two halves, corresponding with the repetition of the organs it supplies on the two sides of the body. Besides these principal centres, we meet with numerous smaller ones upon the nervous cords (*f*, *f*, *g*, *g*), which proceed from them to the different parts of the general muscular envelope or mantle; and in the *Pecten* there is a series of distinct eyes along the margin of the mantle, each of which has a small ganglion in immediate relation with it.

853. Now it will be observed that the two cephalic ganglia (*a*, *a*) are connected with the pedal ganglion (*b*) by means of a pair of trunks proceeding from the former to the latter; and that they are, in like manner, separately connected with the respiratory or branchial ganglion (*c*). There is good reason to believe that the *pedal* and *branchial* ganglia minister to the purely *reflex* actions of the organs they respectively supply, and that they would serve this purpose as well if altogether cut-off from connection with the cephalic ganglia; whilst the *cephalic*, being the instruments of the actions which are called-forth by sensation, exert a general control and direction over the movements of the animal, through the medium of the trunks by which they communicate with the ganglia in immediate connection with the muscular apparatus. It is difficult, however, to make satisfactory experiments upon this subject in these animals, their movements being for the most part slow and feeble, and their nervous system not readily accessible; and our idea of the respective functions of their ganglia is chiefly founded upon the distribution of their nerves, and upon the analogous operations of the ganglia that correspond to them in other animals.

854. In ascending through the Molluscous series, we find the Nervous system increasing in complexity, in accordance with the general organization of the body; the addition of new organs of

special sensation, and of new parts to be moved by muscles, involving the addition of new ganglionic centres whose functions are respectively adapted to these purposes. But we find no other multiplication of *similar* centres than a doubling on the two sides of the body, excepting in a few cases in which the organs they supply are correspondingly multiplied. Of this we have a very characteristic example in the arms of the Cuttle-fish, which are furnished with great numbers of contractile suckers, every one possessing a ganglion of its own. Here we can trace very clearly the distinction between the *reflex* actions of each individual sucker, depending upon the powers of its own ganglion; and the movement prompted by sensation, which results from its connection with the cephalic ganglia. The nervous trunk which proceeds to each arm may be distinctly divided into two tracts; in one of which are contained the ganglia which peculiarly appertain to the suckers, and which are connected with them by distinct filaments; whilst in the other there is nothing but tubular structure, forming a direct communication between these and the cephalic ganglia; so that each sucker has a separate relation with a ganglion of its own, whilst all are alike connected with the cephalic ganglia, and are placed under their control. We see the results of this arrangement in the mode in which the contractile power of the suckers may be called into operation. When the animal embraces any substance with its arm (being directed to this action by its sight or other sensation), it can bring all the suckers simultaneously to bear upon it; evidently by a determinate impulse transmitted along the connecting cords that proceed from the cephalic ganglia to the ganglia of the suckers. On the other hand, any individual sucker may be made to contract and attach itself, by placing a substance in contact with it alone; and this action will take-place equally well when the arm is separated from the body, or even in a small piece of the arm when recently severed from the rest,—thus proving that when it is directly excited by an impression made upon itself, it is a *reflex* act quite independent of the cephalic ganglia, not involving sensation, and taking-place through the medium of its own ganglion alone.

855. In the Molluscous classes, generally speaking, the Nervous system bears but a small proportion to the whole mass of the body; and the parts of it which minister to the *general* movements of the fabric, are often small in proportion to those which serve some *special* purpose, such as the actions of respiration. This is what we should expect from the general inertness of their character, and from the small amount of muscular structure which they possess.— On the other hand, in the *Articulated* classes, in which the locomotive apparatus is highly developed, and its actions of the most energetic kind, we find the Nervous system almost entirely subservient to this function. In its usual form, it consists of a chain

of ganglia connected by a double cord; commencing in the head, and passing backwards through the body (Plate II., Fig. 2). The ganglia, though they usually appear single, are really double; being composed of two equal halves, sometimes closely united on the median line, but occasionally remaining separate like the cephalic ganglia of the Solen (Fig. 1, *a*, *a*), and being united together by a transverse commissural trunk. In like manner, the longitudinal cord, though really double (as seen in the upper part of Fig. 2), often appears to be single, in consequence of the close approximation of its lateral halves (as in the lower part of Fig. 2). In general we find a ganglion in each segment, giving-off nerves to the muscles of the legs, as in Insects, Centipedes, &c.; or to the muscles that move the rings of the body when no extremities are developed, as in the Leech, Worm, &c. In the lower vermiform (or Worm-like) tribes, especially in the marine species, the number of segments is frequently very great, amounting even to several hundreds; and the number of ganglia follows the same proportion. Whatever be their degree of multiplication, they seem but repetitions of one another; the functions of each segment being the same with those of the rest. The *cephalic* ganglia, however, are always larger and more important; they are connected with the organs of special sense; and they evidently possess a power of directing and controlling the movements of the entire body, whilst the power of each ganglion of the trunk is confined to its own segment.—The longitudinal ganglionic cord of Articulata occupies a position which seems at first sight altogether different from that of the nervous system of Vertebrated animals; being found in the neighbourhood of the *ventral* or inferior surface of their bodies, instead of lying just beneath their dorsal or upper surface. There is reason, however, for regarding the *whole* of the body of these animals as having an inverted position; so that they may be considered as really crawling upon their backs. On this view, their longitudinal nervous tract corresponds with the spinal cord of Vertebrata in *position*, as we shall find that it does in *function*.

856. We shall draw our chief illustrations of the structure of the nervous system in the Articulated series, from the class of *Insects*, in which it has been particularly examined. In these Animals, the number of segments never exceeds twelve (exclusive of the head), either in their larva, pupa, or imago state; and the total number of pairs of ganglia, therefore, never exceeds thirteen, including the cephalic ganglia. These in the larva are nearly equal in size, one to another (Plate II., Fig. 2, *a*, and 1—12); the functions of the different segments of the body being almost uniform, and the development of the organs of special sense not being such as to involve any considerable predominance in the size of the cephalic ganglia. We observe at

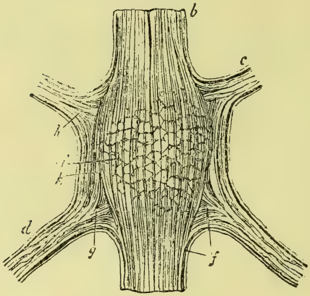
the anterior extremity the pair of cephalic ganglia (*a*), from which proceeds, on each side, a cord of communication to the first ganglion (I) of the trunk. This double cord, with the ganglia above and below, thus forms a ring which embraces the œsophagus; the cephalic ganglia being situated on the upper side of it, whilst the ganglionic column of the trunk lies beneath the alimentary canal along its whole length. In the *Sphinx ligustri*, or Privet Hawk-moth, the nervous system of whose larva is here represented, the last two segments of the body are drawn-together, as it were, into one; and instead of distinct 11th and 12th ganglia, we find but a single mass nearly double the size of the rest, and obviously formed of the elements that would have otherwise gone to form the two.

857. When the structure of the chain of ganglia is more particularly inquired-into, it is found to consist of two distinct *tracts;* one of which is composed of nervous fibres only, and passes backwards from the cephalic ganglia, over the surface of all the ganglia of the trunk; whilst the other includes the ganglia themselves. Hence every part of the body has two sets of nervous connections; a direct one with the ganglion of its own segment, and an indirect with the cephalic ganglia. Impressions made upon the afferent fibres which proceed from any part of the body to the cephalic ganglia, give rise to *sensations* when conveyed to the latter; whilst, in respondence to these, the influence of sensations received by the cephalic ganglia, and operating through them, harmonizes and directs the general movements of the body, by means of the communicating cords proceeding from them. For the *reflex* operations, on the other hand, the ganglia of the ventral cord are sufficient; each one ministering to the actions of its own segment, and, to a certain extent also, to those of other segments. It has been ascertained by the careful dissections of Mr. Newport, that of the fibres constituting the roots by which the nerves are implanted in the ganglia, some pass into the vesicular matter of the ganglion, and, after coming into relation with its vesicular substance, pass-out again on the same side (Fig. 228, *f*, *k*); whilst a second set, after traversing the vesicular matter, passes-out by the trunks proceeding from the opposite side of the same ganglion; and a third set runs along the portion of the cord (*b*) which connects the ganglia of different segments, and enters the nervous trunks that issue from them, at a distance of one or more ganglia above or below. Thus it appears that an impression conveyed by an *afferent* fibre to any ganglion, may excite a motion in the muscles of the same side of its own segment, or in those of the opposite side, or in those of segments at a greater or less distance, according to the point at which the *efferent* fibres leave the cord.

858. The general conformation of Articulated animals, and the

arrangement of the parts of their nervous system, render them peculiarly favourable subjects for the study of the *reflex* actions; some of the principal phenomena of which will now be described.

Fig. 228.*



If the head of a Centipede be cut-off whilst it is in motion, the body will continue to move onwards by the action of its legs; and the same will take place in the separate parts, if the body be divided into several distinct portions. After these actions have come to an end, they may be excited again by irritating any part of the nervous centres or the cut extremity of the nervous cord. The body is moved forwards by the regular and successive action of the legs, as in the natural state; but its movements are always forwards, never backwards, and are only directed to one side when the forward movement is checked by an interposed obstacle. Hence although they might *seem* to indicate consciousness and a guiding will, they do not so in reality; for they are carried on, as it were, mechanically; and show no direction of object, no avoidance of danger. If the body be opposed in its progress by an obstacle of not more than half of its own height, it mounts over it and moves directly onwards, as in its natural state; but if the obstacle be equal to its own height, its progress is arrested, and the cut extremity of the body remains forced-up against the opposing substance, *the legs still continuing to move.*— If, again, the nervous cord of a Centipede be divided in the middle of the trunk, so that the hinder legs are cut-off from connection with the cephalic ganglia, they will continue to move, but not in

* Portion of the ganglionic tract of *Polydesmus maculatus: b*, inter-ganglionic cord; *c*, anterior nerves; *d*, posterior nerves; *f, k*, fibres of reflex action; *g, h*, commissural fibres; *i*, longitudinal fibres, softened and enlarged as they pass through ganglionic matter.

harmony with those of the fore-part of the body; being completely paralysed, as far as the animal's controlling power is concerned, though still capable of performing reflex movements by the influence of their own ganglia, which may thus continue to propel the body in opposition to the determinations of the animal itself.— The case is still more remarkable when the nervous cord is not merely divided, but a portion of it is entirely removed from the middle of the trunk: for the anterior legs still remain obedient to the animal's control; the legs of the segments from which the nervous cord has been removed are altogether motionless; whilst those of the posterior segments continue to act through the reflex powers of their own ganglia, in a manner which shows that the animal has no power of checking or directing them.

859. The stimulus to the reflex movements of the legs, in the foregoing cases, appears to be given by the contact of the extremities with the solid surface on which they rest. In other cases, the appropriate impression can only be made by the contact of liquid; thus a Dytiscus (a kind of water-beetle) having had its cephalic ganglia removed, remained motionless so long as it rested upon a dry surface: but when cast into water, it executed the usual swimming motions with great energy and rapidity, striking all its comrades to one side by its violence, and persisting in these for more than half an hour. Other movements, again, may be excited through the respiratory surface. Thus, if the head of a Centipede be cut-off, and, while the trunk remains at rest, some irritating vapour (such as that of ammonia or muriatic acid) be caused to enter the air-tubes on one side of it through the spiracles of that side (§ 659), the body will be immediately bent in the opposite direction, so as to withdraw itself as much as possible from the influence of the vapour; if the same irritation be then applied on the other side, the reverse movement will take place; and the body may be caused to bend in two or three different curves, by bringing the irritating vapour into the neighbourhood of different parts of either side. The movement is evidently a reflex one, and serves to withdraw the entrances of the air-tubes from the source of irritation; in the same manner as the acts of coughing and sneezing in the higher animals cause the expulsion, from their air-passages, of solid, liquid, or gaseous irritating matters which may have found their way into them.

860. From these and similar facts it appears that the ordinary movements of the legs and wings of Articulated animals are of a reflex nature, and may be effected solely through the ganglia with which these organs are severally connected; whilst in the perfect being they are harmonized, controlled, and directed by the instinctive guidance, which depends upon sensations acting through the cephalic ganglia and the fibres proceding from them.

There is strong reason to believe, that the operations to which these ganglia are subservient are almost entirely of a *consensual* nature (§ 845); being immediately prompted by Sensations, chiefly those of sight, but seldom depending on any processes of a truly rational character. When we attentively consider the habits of these animals, we find that their actions, though evidently directed to the attainment of certain ends, are very far from being of the same spontaneous nature, or from possessing the same *designed* adaptation of means to ends, as those performed by ourselves or by the more intelligent Vertebrata under like circumstances. We judge of this by their unvarying character, the different individuals of the same species executing precisely the same movements when the circumstances are the same; and by the very elaborate nature of the mental operations which would be required, in many instances, to arrive at the same results by an effort of reason. Of such we cannot have a more remarkable example than is to be found in the operations of Bees, Wasps, and other social Insects; which construct habitations for themselves upon a plan which the most enlightened human intelligence, working according to the most refined geometrical principles, could not surpass; but which yet do so without education communicated by their parents, or progressive attempts of their own, and with no trace of hesitation, confusion, or interruption,—the different individuals of a community all labouring effectively for one common purpose, because their instinctive or consensual impulses are the same.

861. It is interesting to remark, that in the change from the Larva to the perfect or Imago state of the Insect, the Cephalic ganglia undergo a great increase in size (Plate II., Fig. 3, *a*, *a*). This evidently has reference to the increased development of the organs of special sense in the latter; the eyes being much more perfectly formed, antennæ and other appendages used for feeling being evolved, and rudimentary organs of hearing and smell being added. In respondence to the new sensations which the animal must thus acquire, a great number of new instinctive actions are manifested; indeed it may be said that the instincts of the perfect Insect have frequently nothing in common with those of the Larva. The latter have reference to the acquirement of food; the former chiefly relate to the acts of reproduction, and to the provisions requisite for the deposit and protection of the eggs and for the early nutrition of the young.—We find another important change in the nervous system of the adult or perfect Insect; namely, the concentration of the ganglionic matter of the ventral cord in the thoracic region (*e*, *f*); with the three segments of which, the three pairs of legs and the two pairs of wings are connected. The nine segments of the abdomen in the perfect Insect give attachment to no organs of motion, and are seldom

themselves very moveable; and we find that the ganglia which correspond with them have undergone no increase in size, but have rather diminished, and have sometimes almost completely disappeared. Where the last segment, however, is furnished with a particularly moveable appendage, such as a sting or an ovipositor, we always find a large ganglion in connection with it.

862. These ganglia of the ventral cord evidently correspond in function with the *pedal* ganglion of the Mollusca; being so many repetitions of it, in accordance with the number of members. We have now to speak of a system of *respiratory* ganglia, which also are repeated in like manner, in accordance with the condition of the respiratory apparatus; this being diffused through the whole body in most of the Articulata, instead of being restricted to one spot as in the Mollusca. The system of respiratory nerves consists of a chain of minute ganglia, lying upon the larger cord, and sending-off its delicate nerves between those that proceed from the ganglia of the latter, as shown in Plate II., Fig. 2. These respiratory ganglia and their nerves are best seen in the thoracic portion of the cord, where the strands of communication between the pedal ganglia diverge or separate from one another. And this is particularly the case in the Pupa state, when the whole cord is being shortened, and the divergence of its strands is increased. The thoracic portion of the cord, in the Pupa of the Sphinx ligustri, is shown in Fig. 4; where *a*, *b*, and *c*, represent the 2nd, 3rd, and 4th double ganglia of the ventral cord; *d*, *d*, the cords of connection between them, here widely diverging laterally; and *e*, *e*, the small respiratory ganglia, which are connected with each other by delicate filaments that pass over the ganglia of the ventral cord, and which send-off lateral branches that are distributed to the air-tubes and other parts of the respiratory apparatus, communicating with those of the other system.

863. Besides the Respiratory system of ganglia and nerves, there is in Insects, as in some Mollusks, a set of minute ganglia which is especially connected with the acts of mastication and swallowing; its filaments being distributed to the muscles of the mouth and pharynx, and some of its ganglia being even found on the stomach, where that organ is remarkable for its muscular powers. The number and arrangement of these ganglia vary considerably in different animals, even in those of the same group; but some traces of this distinct system, which is designated as the *stomato-gastric*, may always be found. One of the minute ganglia appertaining to it, and forming its anterior termination, is seen to lie on the median line in front of the great cephalic ganglia (Plate II., Fig. 3, *c*). From this a trunk passes backwards along the œsophagus; which may be likened to the œsophageal branches of the Par vagum in Vertebrata. The other small ganglia communicating with this are seen at *d*, *d*.

864. We are not without traces, moreover, among Invertebrat animals, of the *Sympathetic* system of the higher classes; but it i quite a mistake to compare the *entire* system of nerves and gangli in the former with the Sympathetic system of the latter, as wa formerly done. The chief distribution of the branches of th Sympathetic of Vertebrata is upon the walls of the blood-vessels and upon the muscular substance of the heart and alimentar canal; and it is by the passage of some of the filaments from th system of minute ganglia just pointed-out to the dorsal vessel that we recognize it as combining the functions of the Sympatheti with those of the gastric and cardiac portions of the Par vagum It will be remembered that there is a frequent inosculatio between these two nerves, even in the higher animals.

865. Thus we have seen that in Invertebrate animals, the Nervous System consists of a series of isolated ganglia, connected together by fibrous trunks. The number of these ganglia and the variety of their functions correspond with the number and variety of the organs to be supplied. In the lowest Mollusca, the regulation of the ingress and egress of water seems almost the only function to be performed; and here we have but a single ganglion. In the Star-fish we have five or more ganglia; but they are all repetitions one of another, and are obviously the centres of action to the several segments to which they respectively belong, neither having a predominance over the rest. And in the higher Mollusca and Articulata, we have a ganglion, or more commonly a pair of ganglia, situated at the anterior extremity of the body, connected with the organs of special sensation, and evidently exerting a dominant influence over the rest. In the lower Mollusca, we have but a single ganglion for general locomotion; but this is doubled laterally and repeated longitudinally in the Articulata, in accordance with the multiplication of their locomotive organs, so as to form the ventral cord. In like manner, the Mollusca possess a single ganglionic centre for the respiratory movements; and this is repeated in every segment of the higher Articulata, forming a chain of respiratory ganglia, which regulates the actions of the extensively diffused respiratory apparatus of these animals. The acts of mastication and deglutition, again, in both sub-kingdoms, are immediately dependent upon a distinct set of ganglionic centres; which are connected, however, like the preceding, with the cephalic ganglia. And we have further seen that wherever special organs are developed, whose operations depend upon muscular contraction, ganglionic centres are developed in immediate relation with them; so as to enable them to act by their simple reflex power, as well as under the direction of the cephalic ganglia, as is the case with the suckers of the Cuttle-fish.—Now when we inquire into the relation of the *cephalic ganglia* of Invertebrata to the Brain of the

igher Vertebrate animals, we find that these organs cannot be ompared in their totality; for the former are the representatives f a certain portion only, and that usually but a small one, of the atter. The cephalic ganglia of the Centipede, for example, eceive nerve-trunks from the eyes, the antennæ, and other ensory organs, and give-off motor nerves to the different move- ble parts of the head; and the history of their development, vhich has been studied by Mr. Newport, shows that they may be onsidered as the coalesced ganglia of the four segments of which he anterior part of the head is composed; while the first sub- œsophageal ganglia are formed by the coalescence of the four segments entering into the composition of the posterior part of the ead. The increased bulk of the cephalic ganglia in the higher Articulata, and especially in the perfect Insect, is obviously for the most part dependent upon the increased development of the visual apparatus, for we find it everywhere proportional to this; and hence we may look upon them as mainly *optic* ganglia, serving to direct the actions of the animal through the sense of sight.—There is no part of those organs which can be considered as *superadded* to the ganglionic masses which are the immediate centres of the cephalic nerves; consequently there is nothing which can be certainly likened either to the Cerebrum or to the Cerebellum of Vertebrata. And the representative of these cephalic ganglia in the Vertebrate Encephalon, is that series of ganglionic centres at the base of the brain, which constitute (as we shall presently find) its fundamental portion, and with which all the cephalic nerves are immediately connected.

866. When we direct our attention to the Nervous system of the *Vertebrate* series, we perceive that it differs from that of the Invertebrate classes we have been considering, in two remarkable features.—In these last it has seemed but as a mere appendage to the rest of the system, designed to bring its several parts into more advantageous relation. On the other hand, in the Vertebrata the whole structure appears subservient to it, and designed but to carry its purposes into operation.—Again, in the Invertebrata we do not find any special adaptation of the organs of support for the protection of the Nervous System; for it is either inclosed with the other soft parts of the body in one general hard tegument, as in the Star-fish and other Echinodermata, and in Insects, Crus- tacea, and other Articulata; or it receives a still more imperfect protection, or even none at all, as in the Mollusca. Now in the Vertebrata we find a special and complex bony apparatus, adapted in the most perfect manner for the protection of the Nervous system; and it is, in fact, the possession of a jointed Spinal column, and of its Cranial expansion, which best characterizes the group.

867. The Nervous System of Vertebrata is not merely remark-

able for its high development, relatively to the remainder of t structure: it is also distinguished by the possession of parts which we have nothing analogous in the lower tribes, and by t mode in which these are concentrated and combined, so as to for one continuous mass, instead of consisting of a series of scatter ganglia.—The chief parts which are newly introduced (so to speal in this sub-kingdom, are the Cerebral hemispheres and Cerebellun of which there are no traces whatever in the lower Articulata ar Mollusca, and but very doubtful representations in the highes These are superimposed, as it were, upon the Cephalic ganglia cor nected with the organs of special sense, and upon the cords th connect them with the first ganglion of the trunk.—Again, w find that the locomotive ganglia, which formed the long knotte cord of the Articulata, are united with the centres of the respirator system, and with those of the stomato-gastric system, to form on continuous tract, which commences anteriorly from the ganglia c special sense, and runs backwards* without interruption, in th canal of the Vertebral column, forming the Spinal Cord. This i a *continuous* instead of an *interrupted* ganglionic mass; it is com posed of two lateral halves, precisely similar to each other; an each of these consists of two parts, as distinct from each other a the two tracts in the ventral cord of the Articulata,—namely, *fibrous* structure, which connects every part of it with the Ence phalon (or collection of nervous masses within the cranium), an which also serves to connect together the different parts of th cord itself,—and a *vesicular* portion, which forms the proper centr of a portion of the fibres entering into the roots of those nerves The upper portion of the Spinal cord, which is prolonged into th cranium, and comes into immediate relation with the Encephalon is termed the *Medulla Oblongata.* It is in this that the centres o the respiratory and stomato-gastric nerves are found; the situation of these important ganglia within the Cranium being obviously destined to protect them from those injuries to which the Spinal Cord itself is liable.

868. Thus, then, we are led to recognize in the Nervous system of Vertebrata the following fundamental parts.—1. A system of ganglia subservient to the reflex actions of the organs of *locomotion*, and corresponding with the chain of pedal or locomotive ganglia that makes-up the chief part of the ventral cord of the Articulata; in this system, the grey or vesicular matter forms one continuous tract, which occupies the interior of the *Spinal Cord.*—2. A ganglionic centre for the movements of *respiration*, and another for those of *mastication* and *deglutition*; these, with part of the preceding, make-up the proper substance of the *Medulla Oblongata.*—3. A series of ganglia in immediate connection with

* When we speak of the Vertebrata generally, their bodies are of course supposed to be in a horizontal position,—not vertical, as in Man.

ıe organs of *Special Sense;* these are situated within the cranium, t the anterior extremity of the Medulla Oblongata; and in the ›west Vertebrata they constitute by far the largest portion of the ntire Encephalon.—4. The *Cerebellum*, which is a sort of off-hoot from the upper extremity of the Medulla Oblongata, lying ehind the preceding.—5. The *Cerebral Hemispheres*, a pair of anglionic masses which lie upon the ganglia of special sense, apping them over more or less completely, according to their elative development.—These last two organs exist in the lowest 'ertebrata, as in Invertebrate animals generally, in quite a rudi-ıentary state; but their development, relatively to other parts of ıe Encephalon, and to the entire bulk of the animal, increases as re ascend the scale; so that in Man and the higher Mammalia ıey constitute by far the larger portion of the Nervous centres, nd are essential to the greater part of the operations of the Ner-ous system. The development of the *Cerebral Hemispheres* bears close relation to the increase of the *Intelligence*, and to the pre-ominance of the *Will* over the involuntary impulses. The in-reased size of the Cerebellum, on the other hand, seems connected rith the necessity which exists for the adjustment and combina-ion of the locomotive powers, when the variety in the movements erformed by the animal is great, and a more perfect harmony is equired among them.—A sketch of the mode in which these ifferent parts are combined and arranged in the several classes of 'ertebrata, and of their relative development in each, will aid us ı the subsequent more detailed examination of their functions.

869. In the class of *Fishes*, taken as a whole, the Encephalon ›ears a much smaller proportion to the Spinal Cord, than it does ı the higher Vertebrata. In the curious *Amphioxus* or Lancelet, here is no discoverable nervous mass above the Medulla Oblongata; so that this animal is regularly formed upon the plan which occa-sionally presents itself as a monstrosity in Man,—namely, having the Spinal Cord and Medulla Oblongata for the whole of the ıervous centres, and being *anencephalous* or destitute of any proper Encephalon. In some of the lowest Vermiform (worm-like) Fishes, such as the Lamprey, the cephalic masses are very little more de-veloped in proportion to the Spinal Cord, than are the cephalic ganglia of Insects in reference to their chain of ventral ganglia. But as the organs of special sense acquire a more complete evolu-tion, we find the ganglia connected with them presenting a greatly increased size. On opening the cranial cavity of a Fish, we usually observe four nervous masses (three of them in pairs) lying, one in front of the other, nearly in the same line with the Spinal cord. The first or most anterior of these are the *Olfactory ganglia* (Plate II., Figs. 5, 6, 7, *a*), or the ganglia of the nerves of smell; the nature of which is known from their being situated ıt the origin of the Olfactory nerves. In the Shark and some

other Fishes, these are separated from the rest by peduncles or footstalks; a fact of much interest, as explaining the arrangements which we find in Man. What is commonly termed the *trunk* of *his* Olfactive nerve is really the commissure connecting the Olfactive ganglion (known as the bulbous enlargement that lies upon the cribriform plate of the ethmoid bone) with the other portions of his Encephalon; the proper fibres of the nerve being those which come-off from this ganglion, in the numerous branches that proceed from it into the nasal cavity. Behind the Olfactive ganglia is a pair of masses (*b*, *b*), of which the relative size varies greatly in different Fishes. Thus in the Perch, whose Encephalon is here figured, their size is intermediate between that of the first and third pairs; being as much inferior to that of the third, as it is superior to that of the first. On the other hand, in the Shark and several other Fishes, they are considerably larger than the succeeding pair. These second ganglia are commonly considered as the rudiments of the *Cerebral hemispheres;* but there seems reason for regarding them as chiefly the representatives of the *Corpora Striata;* the existence of a Cerebrum being only indicated by a thin layer of vesicular matter, which overlies the ventricle that is found in these bodies in the brains of Cartilaginous Fishes alone.—Behind them, and forming the third pair of ganglionic masses (*c*, *c*), are two large bodies, from which the optic nerves arise; these evidently represent the *Optic ganglia,* which constitute the principal mass of the cephalic ganglia in Insects and the higher Mollusca, and with which the Corpora Quadrigemina of higher Vertebrata partly correspond; but they probably represent also the *Thalami Optici* of the brain of Man and the higher animals.—At the back of these, overlying the top of the spinal cord, is a single mass (*d*), the *Cerebellum.* This, also, varies greatly in its relative dimensions, being much more highly developed in the active and rapacious Sharks, than it is in Fishes of inferior muscular energy and variety of movement. — The Spinal Cord (*e*) is divided at the top by a fissure, which is most wide and deep beneath the Cerebellum, where there is a complete separation between its two halves. This opening corresponds to that through which the œsophagus passes in the Invertebrata; but as the entire nervous mass of Vertebrated animals lies above the alimentary canal (or nearer the dorsal surface), it does not serve the same purpose in them; and in the higher classes the fissure is almost entirely closed by the union of the two halves on the median plane, the *fourth* ventricle, however, being a remnant of it. This cavity is partly seen in Fig. 7, which is a vertical section of the brain whose upper and under surfaces are shown in Figs. 5 and 6.—In the lateral strands of the Medulla Oblongata, close to the fourth ventricle, there is a pair of ganglionic centres (characterized by the presence of vesicular matter) in which the

Auditory nerve terminates; and these are sometimes developed as distinct ganglionic enlargements. Other separate ganglia, sometimes of considerable size, are very commonly found at the origin of the Par Vagum.—It is curious to notice the very large comparative size of the Pineal gland (*f*), and of the Pituitary body (*h*), in this class; the functions of these organs are entirely unknown.

870. The analogy of the Optic lobes of Fishes to the Corpora Quadrigemina and Thalami Optici of the fully-formed brain of the higher Vertebrata, is not so complete as it is to certain parts which occupy their place at an earlier period; the mode in which these parts originate being the same in all Vertebrata, and the special arrangements proper to each class becoming gradually apparent. We have already seen (§ 810) that the foundation of the Cerebro-spinal Axis is laid in the *primitive trace;* a canal being formed by the meeting of the dorsal laminæ on the median line, which dilates anteriorly into a bulbous enlargement, and terminates posteriorly in a point. The bulbous enlargement soon presents a division into three distinct compartments, which are known as the three *Cerebral vesicles* (Fig. 229); and from these all the different parts of the Encephalon are progressively developed. The first or most anterior (1) gives origin to the Cerebral hemispheres; the second or middle (2) to the Optic ganglia; and the third or most posterior (3) to the Medulla Oblongata. All three vesicles at this time are hollow, and their cavities freely communicate with each other. The whole axis, at this time, is very strongly curved (Fig. 230); and the middle vesicle, that of the Optic ganglion, then occupies the most prominent position. The first and third vesicles, in Man and the higher Vertebrata, soon undergo a further division into anterior and posterior; the first into the proper vesicle for the Cerebral hemispheres (Fig. 231, *b*), and a vesicle for the Optic

Fig 229 *

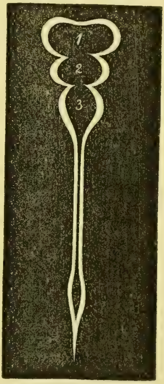


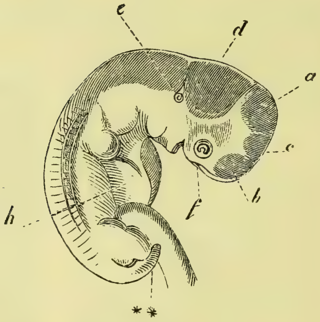
Fig. 230.†

* Formation of Cerebro-Spinal Axis: — 1, Vesicle of Hemispheres; 2, Vesicle of Optic ganglia; 3, Vesicle of Medulla Oblongata.

† Nervous Centres of fœtal Pig, five-eights of an inch long:— 1. Hemispheres; 2, Optic ganglia; 3, Cerebellum; 4, Medulla oblongata.

Thalami (*c*) ; and the third into the vesicle of the Cer bellum (*d*) and the vesicle of the Medulla Oblongata. T vesicle (*a*) of the Optic Ganglia or Corpora Quadrigemina st remains very conspicuous by its relative size and position. T

Fig. 231.*



general disposition of these parts in the early Human embry thus closely corresponds with that which is persistent in Fishes and the separation of the Thalami Optici and Optic ganglia which is here shown, has it parallel in the Lamprey; but th Optic ganglia and the parts surrounding the Third ventricle forr but one lobe in most Fishes, so that the third ventricle seem hollowed-out of the Optic ganglia, as shown in Plate II., Fig 7, *c*.

871. The Encephalon of *Reptiles* does not show any consider able advance in its general structure, above that of the highe Fishes. The Cerebral hemispheres (Plate II., Figs. 8, 9, 10, *b* are always much larger than the Olfactive and Optic ganglia and they generally cover-in the latter (*c*, *c*) in part, by thei posterior extremities. The Cerebellum is almost invariably o small proportionate dimensions ; and this is especially the case ir the Frog, in which it does not even cover-in the fourth ventricle This low development of the Cerebellum in Reptiles is wha might be anticipated from the general inertness of these animals

* Human Embryo of sixth week, enlarged about three times :—*a*, vesicle of Corpora Quadrigemina ; *b*, vesicle of Cerebral Hemispheres ; *c*, vesicle o Thalami Optici and third ventricle; *d*, vesicle of Cerebellum and Medulla ob- longata ; *e*, auditory vesicle; *f*, olfactory fossa ; *h*, liver; ** caudal extremity.

d the want of variety in their movements. The Spinal Cord still very large, in proportion to the nervous masses contained the skull; and, as we shall hereafter see, its power of keeping the movements of the body, after it has been cut-off from all nnection with the brain, is very considerable.—We find that Reptiles, as in Fishes, the Spinal Cord may have a nearly iiform size from one extremity to the other, like the ventral rd of the lower Articulata; or it may present considerable ılargements at particular spots, like the ganglionic cord in the oracic region of Insects. This difference depends upon the gree of development of the special locomotive organs. Thus the Eel and Serpent, whose movements are accomplished by e undulations of the entire trunk, and which are destitute of embers, we find a uniform development of ganglionic matter in e spinal cord. On the other hand, in the Flying-fish, in which e pectoral fins or anterior extremities effect the greater part of e propulsion of the body, we find a great ganglionic enlargement of the Spinal cord at the part with which the nerves of ose members are connected; in the Frog, whose movements are iiefly effected by the posterior extremities, we find a similar ılargement at the roots of the crural nerves; and in the Turtles ıd Lizards, the two pairs of whose members are nearly similar function, and serve to effect the principal movements of the ody, we find an anterior and posterior enlargement of the Spinal ord corresponding to the parts with which the nerves of these embers are connected.

872. We find in *Birds* a considerable advance in the character the Encephalon, towards that which it presents in Mammalia. he Cerebral hemispheres (Plate II., Figs. 11, 12, 13, *b*) are eatly increased in size; and they cover-in not merely the lfactory ganglia, but in great part also the optic ganglia. The ormer are of comparatively small size, the organ of smell in irds not being much developed: the latter are very large, in onformity with the acuteness of sight which is highly characteristic of the class. The Cerebellum is of large size, as we hould expect from the number and complexity of the muscular ıovements performed by animals of this class; but it consists hiefly of the central lobe, with little appearance of lateral emispheres. The Spinal Cord is still of considerable size in omparison with the Encephalon; and it is much enlarged at the oints whence the legs and wings originate. In the species which ave the most energetic flight, such as the Swallow, the enlargement is the greatest where the nerves of the wings come-off; ıt in those which, like the Ostrich, move principally by running ı the ground, the posterior enlargement, from which the legs are pplied with nerves, is much the more considerable.

873. In the *Mammalia*, we find the size and general develop-

ment of the Encephalon presenting a gradual increase, as we ascend the series from the non-placental Monotremes and Marsupials towards Man. In the former, the Hemispheres exhibit no convolutions; and the great transverse commissure, or connecting band of fibrous structure, termed the *corpus callosum*, is nearly deficient. As we rise through the true viviparous division of the class, we notice a gradually-increasing prolongation of the Cerebral hemispheres backwards; so that first the Optic ganglia and then the Cerebellum are covered-in by them. The latter partly shows itself, however, in all but Man and the Quadrumana, when we look at the brain from above downwards; as we see in the Encephalon of the Sheep (Plate II., Figs. 14, 15, *d*). The Cerebral hemispheres increase not only in size, but also in complexity of structure both external and internal. Their exterior, instead of remaining smooth, is marked by convolutions, which serve to extend very greatly the amount of surface over which blood-vessels can pass into the grey substance. Their internal structure becomes more complex, in the same proportion as their size and the depth of their convolutions increase; and in Man all these conditions present themselves in a far higher degree than in any other animal. The number of commissural bands connecting the two hemispheres with each other transversely, and uniting their anterior and posterior portions, is very greatly increased; and, in fact, a large proportion of their mass is composed, in Man and the higher Mammalia, of fibres of this character.— In proportion to the increase of the Cerebral hemispheres, there is a relative diminution in the size of the ganglia of special sense; but their dimensions, as compared with the entire bulk of the animal, are by no means reduced, but are even increased. The Olfactive ganglia (Fig. 14, *a*) are always readily discoverable, being separated from the remainder of the encephalic masses by a peduncle on each side. The Optic ganglia (Fig. 15, *c*) on the other hand, are so completely covered-in by the Hemispheres, that it is only when the latter are turned-aside that we can discern them. They differ in external aspect from the optic ganglia of Birds and the lower Vertebrata; being divided by a transverse furrow into anterior and posterior eminences, whence they are known as the Corpora Quadrigemina. The Auditory ganglia are lodged in the substance of the Medulla Oblongata, forming grey nuclei in the strands termed the 'posterior pyramids;' and grey nuclei nearer its axis, which are the ganglionic centres of the Glosso-pharyngeal nerves, perhaps minister to the sense of Taste. Besides these, however, are the two large bodies termed the *Corpora Striata* and *Thalami Optici*, which have been commonly considered as appendages of the Cerebrum, but which must undoubtedly be regarded as distinct from it, and as constituting independent ganglionic centres, whose development bears no

constant proportion to that of the Cerebrum. From the peculiar relation presently to be described (§ 901), which these bodies bear, on the one hand to the Spinal Cord, and on the other to the rest of the Encephalon, there seems strong reason to believe that they together constitute the ganglionic centre of the sense of Touch, and of the motions which are automatically prompted by it.—The Cerebellum is chiefly remarkable for the development of its lateral parts or hemispheres, and for the intricate arrangement of the grey and white matter in them (Fig. 15, *d*); the central portion, sometimes called the vermiform process, is relatively less developed than in those lower Vertebrata in which it forms the entire organ.—The Spinal Cord is much reduced in size, when compared with other parts of the nervous centres; the motions of the animals of this class being more dependent upon their will, or guided by their sensations; and the simply-reflex actions bearing a much smaller proportion to the rest. The development of ganglionic enlargements, in accordance with the presence or absence of high locomotive powers in the extremities, follows the same rule as in the preceding classes.

3. *Functions of the Spinal Cord and its Nerves.*

874. In commencing our more detailed examination into the functions of the different parts of the Nervous system in Vertebrated animals, it seems best to commence with the Spinal Cord; this being the portion whose presence is most essential to the continuance of life. As already mentioned, Infants are sometimes born without any Cerebrum or Cerebellum; and such have existed for several hours or even days, breathing, crying, sucking, and performing various other movements. The Cerebrum and Cerebellum have been experimentally removed from Birds and young Mammals, thus reducing these beings to a similar condition; and all their vital operations have, nevertheless, been so regularly performed, as to enable them to live for weeks or even months. In the Amphioxus, as already remarked, we have an example of a completely-formed adult animal, in which no rudiment of a Cerebrum or Cerebellum can be detected. And in ordinary profound sleep, or in apoplexy, the functions of these organs are so completely suspended, that the animal is for a time, in all essential particulars, in the same condition as if destitute of them. It is possible, indeed, to reduce a Vertebrated animal to the condition (so far as its nervous system is concerned) of an Ascidian Mollusk (§ 850); for it may continue to exist for some time, when not merely the Cerebrum and Cerebellum have been removed from above, but when nearly the whole Spinal Cord has been removed from below,—that part only of the latter being left, which, being the centre of the respiratory actions, corresponds to the single

ganglion of the Tunicata. On the other hand, no animal can exist by its Encephalon alone, the Spinal Cord being destroyed or removed; for the reflex actions of the latter are so essential to the continuance of its Respiration, and consequently of its Circulation, that if they be suspended by the destruction of the portion of the cord which is concerned in them, all the organic functions must soon cease.

875. Although the Spinal Cord was formerly regarded as little else than a bundle of nerves proceeding from the Brain, yet its true rank as a distinct centre of nervous power is now universally admitted. That the actions prompted by it, when these do not originate in one of the higher centres, are of a purely *reflex* nature, consisting in the excitement of muscular movements in respondence to external impressions, without the necessary intervention of sensation,—appears to be a necessary inference from the facts that have been brought to light by experiment and observation. Experiments on the nature of this function are best made upon cold-blooded animals; as their general functions are less disturbed by the effects of severe injuries of the nervous system than are those of Birds and Mammals. When the Cerebrum has been removed, or its functions have been suspended by a severe blow upon the head, a variety of motions may be excited by their appropriate stimuli. Thus, if the edge of the eyelids be touched with a straw, the lid immediately closes. If a candle be brought near the eye, the pupil contracts. If liquid be poured into the mouth, or a solid substance be pushed within the grasp of the muscles of deglutition, it is swallowed. If the foot be pinched, or burned with a lighted taper, it is withdrawn; and (if the subject of the experiment be a Frog) the animal will leap away, as if to escape from the source of irritation. If the cloaca of a Frog be irritated with a probe, the hind-legs will endeavour to push it away. And if acetic acid be applied over the internal condyle of the femur, the foot of the same side will wipe it away; but if this be cut off, after some ineffectual efforts and a short period of inaction, the same movement will be made by the foot of the opposite side.

876. Now the performance of these as well as of other movements, many of them most remarkably adapted to an evident purpose, might be supposed to indicate that *sensations* are called up by the impressions; and that the animal cannot only *feel*, but can *voluntarily direct* its movements, so as to get rid of the irritation which annoys it. But such an inference would be inconsistent with other facts.—In the first place, the motions performed by an animal under such circumstances are never spontaneous, but are always excited by a *stimulus* of some kind. Thus, a decapitated Frog, after the first violent convulsive movements occasioned by the operation have passed away, remains at rest until it is touched;

and then the leg or its whole body may be thrown into sudden action, which immediately subsides again. In the same manner, the act of Swallowing is not performed, except when it is excited by the contact of food or liquid; and even the Respiratory movements, spontaneous as they seem to be, would not continue, unless they were continually re-excited by the presence of venous blood in the vessels or of carbonic acid in the air-cells of the lungs. These movements are all *necessarily* linked with the stimulus that excites them; that is, the same stimulus will always produce the same movement when the condition of the body is the same. Hence it is evident that the judgment and will are not concerned in producing them; and that the *adaptiveness* of the movements is no proof of the existence of consciousness and discrimination in the being that executes them,—the adaptation being made *for* the being, by the peculiar structure of its nervous apparatus, which causes a certain movement to be executed in respondence to a given impression,—not *by* it. An animal thus circumstanced may be not unaptly compared to an automaton, in which particular movements, each adapted to produce a given effect, are produced by touching certain springs. The source of the adaptation is here in the mind of the maker or designer of the automaton; and so it evidently is in the case of the reflex or consensual movements of animals, as well as of those various operations of their nutritive system over which they have no control, yet which concur most admirably to a common end.

877. Again, we find that such movements may be performed, not only when the Brain has been removed, the Spinal cord remaining entire, but also when the Spinal cord has been itself cut across, so as to be divided into two or more portions, each of them completely isolated from each other and from other parts of the nervous centres. Thus, if the head of a Frog be cut-off, and its spinal cord be divided in the middle of the back, so that its fore-legs remain connected with the upper part, and its hind-legs with the lower, each pair of members may be excited to movement by a stimulus applied to itself; but the two pairs will not exhibit any consentaneous motions, as they will do when the spinal cord is undivided. Or, if the Spinal cord be cut across, without the removal of the Brain, the lower limbs may be *excited* to movement by an appropriate stimulus, though they are completely paralyzed to the *will;* whilst the upper remains under the control of the animal as completely as before. Now it is scarcely conceivable that, in this last case, sensation and volition should exist in that portion of the spinal cord which remains connected with the nerves of the posterior extremities, but which is cut-off from the brain. For, if it were so, there must be two distinct centres in the same animal, the attributes of the brain not being affected; and, by dividing the spinal cord into two or more segments, we might thus

create in the body of one animal two or more distinct centres of sensation and will, independent of that which still holds its proper place in the Encephalon. To say that two or more distinct centres of sensation and will are present in such a case, would really be the same as saying that we have the power of constituting two or more distinct *minds* in one body,—which is manifestly absurd.

878. But the best proofs of the limitation of the endowments of the Spinal Cord, are derived from the phenomena presented by the Human subject, in cases where that organ has suffered injury by disease or accident in the middle of the back. We find that when this injury has been severe enough to produce the effect of a complete division of the Cord, there is not only a total want of voluntary control over the lower extremities, but a complete absence of sensation also,—the individual not being in the least conscious of any impression made upon them. When the lower segment of the Cord remains sound, and its nervous connections with the limbs are unimpaired, distinct reflex movements may be excited in the limbs by stimuli directly applied to them; as, for instance, by pinching the skin, tickling the sole of the foot, or applying a hot plate to its surface; and this without the least sensation on the part of the patient, either of the cause of the movement, or of the movement itself. This fact, taken in connection with the preceding experiments both upon Vertebrated and Articulated animals, distinctly proves that sensation is *not* a necessary link in the chain of reflex actions; but that all which is required is an *afferent* fibre, capable of receiving the impression made upon the surface, and of conveying it to the centre; a *ganglionic centre*, composed of vesicular nervous substance, into which the afferent fibre passes; and an *efferent* fibre, capable of transmitting the motor impulse from the ganglionic centre to the muscle which is to be thrown into contraction.

879. These conditions are realized in the Spinal Cord. We may have reflex actions excited through any one isolated segment of it, as through a single ganglion of the ventral cord of Articulata (§ 858); but they are then confined to the parts supplied by the nerves of that segment. Thus if the spinal cord of a Frog be divided just above the origin of the crural nerves, the hind-legs may be thrown into reflex contraction by various stimuli applied to themselves, whilst the fore-legs will exhibit no movement of this kind. But when the brain has been removed, and the Spinal Cord is left entire, movements may be excited in distant parts, as, for example, in the fore-legs, by any powerful irritation of the posterior extremities, and *vice versâ*. This is particularly well seen in the Convulsive movements which take place in certain disordered states of the nervous system; a slight local irritation being sufficient to throw almost any muscle of the body into a state of energetic action (§ 886). And a similar state may be

artificially induced by applying Strychnine (in solution) to the Spinal Cord of a decapitated Frog.

880. The minute anatomy of the Spinal Cord is a subject of great difficulty; and our notions of the course of the fibres within it are rather founded upon physiological phenomena, and upon the more evident structure of the ventral column in Articulata, than upon what can be clearly demonstrated in Vertebrated animals.—The *roots* of each ordinary Spinal Nerve are distinctly separable into an anterior and a posterior fasciculus; and it is certain that these fasciculi have entirely different functions. If they be laid bare and the anterior fasciculus be touched, violent contractions are immediately seen in the muscles supplied by the nerve; these contractions are as strongly manifested if the anterior roots be divided and the ends of their separated parts be irritated; whilst no such result follows, whatever amount of irritation be applied to the ends still in connection with the cord. Notwithstanding these violent movements, the animal shows little or no sign of pain; and such pain as is produced appears to result from the state of *cramp* or violent contraction called forth in the muscles by the strength of the motor excitation.—On the other hand, if the posterior roots be irritated, the animal gives signs of acute pain, and no vigorous muscular contractions are produced. The movements which are witnessed are evidently of a *reflex* nature, being called-forth through the anterior roots; as is proved by their cessation when these are divided. Further, if the posterior roots be divided, and the separated ends be irritated, no effect whatever is produced, no movement being excited, and no sensation being occasioned; but if the ends still in connection with the cord be irritated, the animal shows signs of pain as before.—Hence it is evident that the *posterior* roots are made-up of *afferent* fibres, that is, of fibres which convey impressions *towards* the nervous centres; which impressions, if confined to the Cord itself, excite reflex actions; whilst, if conveyed to the Brain, they call-forth sensations.—On the other hand, it is equally evident that the *anterior* roots are composed of *efferent* or *motor* fibres, which may serve to convey to the muscles the motor impulses originating in the nervous centres; these impulses may be occasioned by the reflex action of the Spinal cord; or they may descend from the Brain, where they have been generated by a consensual, an emotional, or an ideational impulse, or by an act of the Will.

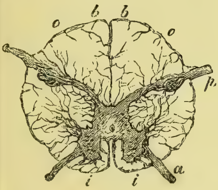
881. Besides the ordinary Spinal nerves, we must rank as belonging to the same series all those arising within the skull, and hence ordinarily ranked as Cranial nerves, the real connections of which are with the intra-cranial prolongation of the Cord; for these minister, like the ordinary Spinal nerves, to common Sensation and Muscular motion, and they have exactly the same relation to the Reflex action of the Spinal Cord itself. We here commonly find, however, that the afferent and efferent

fibres are not mingled in the same trunk, as in the ordinary Spinal nerves, most of the Cranial nerves being *either* sensory or motor, and the third division of the Fifth pair being the only trunk which has a proper double root of its own like that of the Spinal nerves.—Passing from below upwards we find that the First Spinal nerve or *Sub-occipital* (the 10th pair of Willis) not unfrequently arises by a single set of roots from the anterior portion of the cord; and it is then purely motor, except in virtue of its inosculation with other nerves. The *Hypoglossal* (9th pair of Willis) appears to be also a purely motor nerve; arising by one set of roots, and being distributed entirely to the *muscles* of the tongue, which organ derives its sensibility from other nerves. The *Glosso-Pharyngeal* usually arises from a single set of roots, and these correspond with the posterior roots of the Spinal nerves; in some animals, however, and occasionally in Man, there is a distinct anterior root, and the nerve acquires direct motor functions. It may be considered as supplying, with the lingual branch of the Fifth, the posterior root which completes the preceding into an ordinary Spinal nerve; whilst its pharyngeal portion answers to motor branches arising from the roots of the Spinal Accessory or Pneumogastric. The *Spinal Accessory*, again, appears to be chiefly or entirely a motor nerve at its origin; and in like manner the *Pneumogastric*, or Par Vagum, seems at its roots to correspond chiefly with the posterior roots of the ordinary Spinal nerves, and to execute functions analogous to theirs; but these two nerves exchange fibres, so that each acquires in part the endowments of the other. The *Facial* nerve (or portio dura of the 7th), which is the nerve that supplies the muscles of the head in general, arises by a single root, and is exclusively motor in its properties, except in branches which have received sensory filaments by inosculation with other nerves. The same is the case also, with the *Motor Nerves of the Orbit* (the 3rd, 4th, and 6th, of Willis), which arise by single roots, and which have no sensory endowments but those which they obtain by inosculation with the Fifth pair.—On the other hand, the *Fifth* pair arises by a double root; that which corresponds to the anterior or motor root of the Spinal nerves is very small, however, and only enters the Third division of the nerve, which supplies the muscles concerned in mastication; the other root, corresponding with the posterior roots of the spinal nerves, is of large size, and its branches are distributed to the face and head, endowing them with sensibility. Thus the *sensory* division of the Fifth pair, being distributed, not merely to the same parts with its motor division, but also to the parts which derive their motor endowments from the Facial nerve and from the nerves of the Orbit, may be regarded as making-up, together with all of them, one ordinary Spinal nerve.

882. The Spinal Cord is a completely *double* tract; being composed of two distinct halves united together on the median plane

by numerous commissural fibres. This union is much closer in Man and the Mammalia, than it is in the lower Vertebrata; but the division is still marked externally by a deep fissure on the anterior surface of the cord, and by a shallower one on its posterior aspect. Its surface is marked, moreover, by a longitudinal furrow on each side; and into this the *posterior* roots of the nerves dip-down. An anterior furrow has also been described along the line of the *anterior* nerve-roots; but this can scarcely be said to have an actual existence. The surface of the Cord is marked-out by the median fissures and by the lines of origin of the nerve-roots, into the *anterior* columns (Fig. 232, *i*, *i*,), the middle or *lateral* columns (between the anterior roots, *a*, and the posterior roots, *p*), and the posterior columns, *b o*, *b o:* some, however, consider that the lateral or middle columns, being much less completely isolated from the anterior columns than they are from the posterior, should be associated with the former under the name of *antero-lateral* columns. A transverse section of the Cord shows it to contain on each side a crescentic patch of grey or vesicular substance; the points of each crescent are directed towards the anterior and posterior roots of its own side respectively; whilst the convexities of the two crescents approach one another near the median plane, and are connected by a transverse tract, which consists partly of vesicular and partly of fibrous substance. The remainder of the Cord is made-up of white or tubular substance, the course of whose fibres is for the most part longitudinal.—The posterior peak of the crescentic patch of grey matter approaches very closely to the bottom of the posterior furrow; whilst the anterior peak does not come into nearly the same degree of proximity with the surface.

Fig. 232*.



883. Upon tracing the roots of the Nerves into the substance of the Cord, the connection of a part of their fibres with its grey or vesicular matter is easily made evident. Of these fibres, therefore, it serves as the proper ganglionic centre. There is reason to believe, both from anatomical investigation, and from physiological phenomena, that, as in the Articulata (§ 857), a portion of the afferent or excitor fibres, after traversing the grey substance, passes out again in the efferent or motor roots of the *same* side, whilst another portion crosses to the *opposite* side, and forms part

* Transverse Section of Spinal Cord, opposite First pair of Cervical nerves:—*a*, anterior roots; *p*, posterior roots; *i*, *i*, anterior columns; *o*, *o*, posterior columns; *b*, *b*, median portion of these becoming continuous with posterior pyramids.

of *its* efferent trunks. But it is pretty certain that other fibres of the roots become continuous with the longitudinal fibres that form the white strands of the Spinal Cord: of these a small part appears to connect the posterior roots directly with the posterior columns, without passing into the vesicular substance; but the remainder of those belonging to the posterior roots first enter the grey matter of the Cord, and then emerge from it either into the posterior column, or into the posterior part of the lateral column, of their own or of the opposite half of the Cord; and, in like manner, all the longitudinal fibres belonging to the anterior roots first enter the vesicular substance, and then pass out of it again into the anterior column, or the anterior part of the lateral column, of the same or of the opposite side. It would appear from the experimental researches of Dr. Brown-Séquard, that a decussation of the afferent or sensory fibres takes place along the whole length of the Cord; those of the right side passing over to the left, and *vice versâ*. For if one lateral half of the Cord be divided by a transverse section, while the parts below are paralyzed as to *motion* on the *same* side with the section, they are paralyzed as to *sensation* on the *opposite* side. Moreover, a longitudinal section which separates the two lateral halves of the Cord from each other, nearly abolishes the sensibility of the parts below, by dividing the decussating fibres; that which remains being probably due to the ascent of some few fibres either in the grey substance or in the posterior columns of their own side. There can be little doubt that the grey substance is essentially the channel through which sensory impressions are conducted upwards; for if the anterior, posterior, and lateral columns be divided as completely as possible, the grey substance remaining uninjured, the sensibility of the parts below the section continues perfect or nearly so; whilst, however carefully the white columns are preserved from injury, if the grey substance be divided, sensibility is almost totally extinguished. It has been further shown by M. Brown-Séquard, that the central portions of the grey substance are more effective conductors of sensory impressions than either the anterior or the posterior cornua; yet it seems well established that this substance is not itself endowed with sensibility.—The conduction of Motor impulses, on the other hand, appears ordinarily to take place through the anterior and lateral columns and the anterior part of the grey matter; but in the upper part of the cervical region, the anterior columns would not seem to participate in it. The Motor fibres do not decussate, like the sensory, in the Spinal Cord itself; but undergo a complete or nearly complete decussation in the Medulla Oblongata (§ 890); so that while a transverse hemi-section *below* this decussation induces paralysis of movement on the *same* side of the body, a similar section *above* the decussation induces paralysis of movement on the *opposite* side of the body.

884. Whilst, however, there seems good ground for believing that some of the longitudinal strands of the cord form a direct connection between the roots of the Spinal nerves and the Encephalic centres (though probably not passing higher than the Corpora Striata and Thalami Optici, § 901), it would also appear likely that part of those strands consist of *commissural* fibres, which, like those of Insects (§ 857), establish an intimate relation between the several segments of the cord. For the proportions of white substance which present themselves in different parts of its length, are not such as would exist were this substance only a channel of communication between the Brain and the Spinal nerves. Thus in the lower part of the Cervical region, there is an enlargement corresponding with the origins of the nerves that form the brachial plexus; this enlargement is partly caused by an increase in the amount of grey matter; but the amount of fibrous structure, also, is much greater than at the upper part of the cervical region. On the other hand, there is a still greater enlargement of the cord in the Lumbar region, at the part whence the nerves of the lower extremities arise; and this enlargement is caused by the great increase in the amount both of the grey matter and of the white at that point. It may be easily shown by direct measurement, that the fibrous strands of the upper cervical region would not by any means serve to carry onwards to the brain those of the lumbar region alone, much less with the addition of other fibres proceeding from all the intermediate nerves. Further, if the fibrous strands were for the most part (as formerly supposed) directly continuous between the brain and the roots of the spinal nerves, the white portion of the Spinal Cord, in such animals as Serpents, in which it has no ganglionic enlargements, should progressively diminish in diameter with every pair of nerves into which it sends fibres, from its cephalic to its caudal extremity; this, however, is by no means the case, the Spinal Cord of Serpents being remarkable for its uniform diameter throughout.—It is obvious, then, that by far the larger proportion of the white fibres of the Spinal Cord must belong to itself alone, establishing an intimate mutual connection between its different segments and the nerves proceeding from them.

885. Of the particular Reflex actions to which the Spinal Cord (using that term in its limited sense, as excluding the Medulla Oblongata) is subservient, those most connected with the Organic functions have already been noticed. They are chiefly of an *expulsive* kind; being destined to force-out the contents of various cavities of the body. Thus the ordinary acts of Defecation and Urination, Ejaculatio seminis and Parturition, are all reflex actions, over which the Will has a greater or less degree of control; being able to keep the two former ones in check so long as the stimulus is not very violent, and being also capable of

effecting them by itself; but having no control over the two latter, either by way of acceleration or prevention, when once the stimulus by which they are excited has come into full action.—The movements of the posterior extremities are among the most remarkable of those which seem due to the action of the proper Spinal Cord. It has been already noticed (§ 878) that these may be excited, even in Man, when the spinal cord has been severed in the middle without injury to its lower segment; and it is remarkable that gentle stimuli applied to the skin of the sole of the foot appear the most capable of producing them. We have seen how completely, in the lower animals, the acts of progression may be sustained by the repeated stimulus of the contact of the ground or of fluid, without any influence from the Cephalic ganglia (§§ 858, 859); the power of these being limited, it would seem, to the control and direction of them. It is certain that in Birds the movements of flight may be performed after the removal of the Cerebrum. And there is strong reason to believe that so far as the ordinary acts of locomotion are concerned, the movements of the inferior extremities in Man may be performed on the same plan, being sustained by the reflex influence of the successive impulses of the feet upon the ground when once set in action by the Will, whilst we are walking steadily onwards,—the mind being at the same time occupied by some train of thought which engrosses its whole attention. There are few persons to whom it has not occasionally happened, that, on awaking (as it were) from their reverie, they have found themselves in a place very different from that to which they had intended going; and even when the consciousness is sufficiently on the alert to allow sensations to guide, direct, and control the motions of the limbs, their actions appear to be performed without the agency of the Will, which may be entirely concentrated upon some interior mental operation. Movements of this kind may be said to be *voluntary*, being *permitted* by the Will, which is required to start them in the first instance, and which can interfere to check them at any time; but they are not *volitional*, *i. e.*, dependent on the sustaining and directing power of the Will.

886. There are many irregular or abnormal reflex actions, performed through the instrumentality of the Spinal Cord, the study of which is of the highest importance to the Medical Man. It is probable that *all* Convulsive movements are produced through its agency, with that of the Medulla Oblongata and Sensory ganglia; for it has been found, by repeated experiments, that these movements are never produced by injuries of the Cerebral hemispheres. — Convulsive movements may be of three kinds. 1. They may be simply *reflex;* being the natural result of some extraordinary irritation. 2. They may be simply *centric;* depending upon a peculiar condition of the ganglionic centre of the Spinal Cord,

which occasions muscular movements without any stimulation. This may have its origin in an abnormal state of the blood. We know that it may be produced by the introduction of certain poisons (as Strychnia) into the circulation; and it is probable that morbid matters generated within the body may have the same effect. 3. They may depend upon the combined action of both principles; the nervous centres being in a highly irritable state, which causes very slight irritations (such as would otherwise be inoperative) to excite violent reflex or convulsive movements. This last is by far the most common cause of the convulsive actions that occur in various diseased conditions of the system. Thus, convulsions are not unfrequent in children during the period of teething; being produced by the irritation which results from the pressure of the tooth, as it rises against the unyielding gum. In this case the stimulus would scarcely be sufficient to produce the violent result, were it not for a peculiarly excitable state of the Spinal Cord, brought-about by various causes, amongst which impure air and unwholesome food are the most potent. In like manner, when such an excitable state exists, convulsions may be occasioned by the presence of intestinal worms, of irritating substances, or even simply of undigested matters, in the alimentary canal; and will cease as soon as they are cleared-out, in the same manner as the convulsions of teething may often be at once checked by the free lancing of the gums. A change to a purer atmosphere is commonly found the most efficacious means of reducing the morbid excitability of the Spinal Cord, and thus of diminishing the liability to the recurrence of the convulsion.

887. The influence of the condition of the Spinal Cord itself is peculiarly seen in the convulsive diseases termed Hydrophobia, Tetanus, Epilepsy, and Hysteria.— In the first of these, not only the Spinal Cord, but the Medulla Oblongata, and the ganglia of Special Sense, are involved; their peculiar condition being the result, it would appear, of the introduction of a poison into the blood. It is most remarkable that the Cerebrum should so completely escape its influence. When the state of intense excitability in these centres is once established, the slightest stimulus is sufficient to bring-about convulsive movements of the utmost violence. It is characteristic of this complaint, that the stimuli most effectual in exciting the movements, are those which act through the nerves of special sense; thus the *sight* or the *sound* of water will bring-on the paroxysm, and any attempt to *taste* it increases the severity of the convulsions.— In Tetanus there appears to be a similarly excitable state of the Spinal Cord and Medulla Oblongata, not involving the ganglia of special sense. This may be the result of causes altogether internal, as in the idiopathic form of the disease; in which the condition exactly resembles

that which may be artificially induced by the administration of Strychnia, or by its application to the Cord. Or it may be first occasioned by some local irritation, as that of a lacerated wound; the irritation of the injured nerve being propagated to the nervous centres, and establishing the excitable state in them. When the complaint has once established itself, the removal of the original cause of irritation (as by the amputation of the injured limb) is seldom of any avail; since the slightest impression upon almost any part of the body is sufficient to excite the tetanic spasm.—In like manner, Epilepsy, which consists in convulsive actions with temporary suspension of the functions of the Encephalon, may result from the irritation of local causes, like the convulsions of teething; and may cease, like them, when the sources of irritation are removed. But when it becomes confirmed, it seems to involve a disorder of the nervous centres which no local treatment can influence. It appears probable from recent researches, that the suspension of the functions of the Encephalon is due to the spasmodic contraction of its vessels induced by the extension of the reflex motor impulse to the vaso-motor nerves (§ 586).

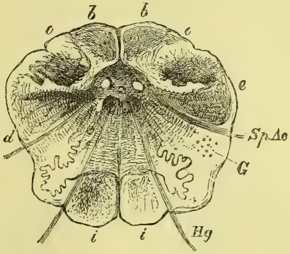
888. These and other forms of Convulsive disorder, when productive of a fatal result, usually act by suspending the respiratory movements; the muscles which effect these being fixed by the spasm, so that the air cannot pass either in or out, and suffocation takes-place as completely as if the entrance to the air-passages were closed. It is remarkable that every one of them may be imitated by *Hysteria;* a state of the nervous system which is characterized by its peculiar excitability, but in which there is no such fixed tendency to irregular action as would indicate any positive disease,—one form of convulsion often taking the place of another, at short intervals, with the most wonderful variety. It will often be found that the convulsions may be immediately traced to some local irritation; thus they are particularly liable to occur at the catamenial periods, especially if the menstrual flux be deficient; but it does not seem improbable, that here too the presence of some morbid matter in the blood has much to do with the development of that peculiar excitability, which gives to slight local irritations such a powerful agency.

4. *Functions of the Medulla Oblongata.*

889. This portion of the nervous centres, as already stated, does not differ in any essential particular from the Spinal Cord, of which it may be considered as a cranial prolongation. But the arrangement of its constituent parts is peculiar; for whilst it is the medium by which the various strands of the Spinal Cord are connected with the different portions of the Encephalon, it is also remarkable as being the ganglionic centre concerned in the main-

tenance of the action of Respiration and in the Ingestion of food. Five principal strands of nervous matter may be distinguished anatomically, in each of its lateral halves (Fig. 233); these are,

Fig. 233*.

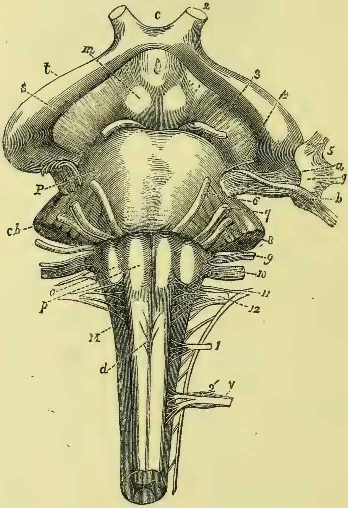


anteriorly, the *Anterior Pyramids* (*i, i*,), next, the *Olivary* bodies, next, the *Lateral* tracts (*d*); next, the *Restiform* bodies (*o, o*); and lastly, the *Posterior Pyramids* (*b, b*). It will be presently seen, however, that the physiological relations of these strands, as indicated by their connections with the Encephalon above, with the Spinal Cord below, and with the nerves that have their centres in them, are very different from what their mere relative positions would indicate.—The grey or vesicular substance in this part, no longer holds the relation to the white that it possesses in the spinal Cord; but is principally aggregated in three pairs of ganglionic centres, of which the *anterior* forms the nucleus of the Olivary body, the *lateral* of the Restiform, and the *posterior* of the Posterior Pyramidal; in addition to which we find a mass (*e*) forming a projection between the Restiform and the Lateral columns, and termed the grey tubercle of Rolando; whilst there is a deeper tract of ganglionic matter, lying near the central commissure, and continuous with that joining the two grey crescents of the Cord, which gives origin below to the Spinal Accessory, next above to the Pneumogastric, next to the Glosso-pharyngeal, and in immediate contiguity with its upper part is the ganglionic centre of the Hypoglossal nerve.

* Transverse Section of Medulla Oblongata through the lower part of the Olivary bodies:— *b b*, posterior pyramids; *o o*, restiform bodies; *e*, grey-tubercle of Rolando; *d*, lateral tract; between which and the anterior pyramids, *i, i*, lie the olivary columns with their corpora dentata and a peculiar collection *e*, of ganglionic cells; *Sp. Ac.*, spinal accessory nerve; *Hg.*, Hypoglossal nerve.

890. The *Anterior Pyramids* (Fig. 234, *p*) consist entirely of fibrous structure, and establish a communication between the motor tract at the base of the Encephalon (which is chiefly derived from the Corpora Striata) and the anterior and antero-lateral columns of the Spinal Cord. They have also a connection with the Cerebellum. Nearly all their fibres decussate (*d*), those that proceed from the right hemisphere passing into the left side

Fig. 234.*



of the cord, and those from the left hemisphere into the right side of the cord; an arrangement which explains the fact, that in Hemiplegia, the paralytic affection of the body is on the side

* Front view of the upper part of the Cranio-Spinal Axis, with the origins of the Nerves;—M, Medulla Oblongata; *p*, anterior pyramids; *d*, their decussation; *o*, olivary bodies; P, Pons Varolii; *c b*, crura cerebelli; *s*, crura cerebri; *m*, corpora mammillaria; *t*, tractus opticus; *c*, chiasma; 2, optic nerve; 3, motor oculi; 4, patheticus; 5, fifth pair; *a*, its larger root; *b*, its smaller root; *g*, Gasserian ganglion; 6, abducens; 7, facial; 8, auditory; 9, glosso-pharyngeal; 10, vagus; 11, spinal accessory; 12, hypo-glossal; 1′, first spinal nerve: 2′, second spinal nerve; *v*, its ganglion.

opposite to that of the lesion of the brain. A small proportion of the fibres of the anterior pyramids does not decussate; and this passes-down, with fibres from the Olivary columns, into the anterior columns of the cord; whilst the decussating fibres dip more deeply away from the anterior surface of the cord, and connect themselves rather with its lateral or middle columns.

891. The *fibrous* portion of the *Olivary* bodies (*o*) is connected above with the Motor tract, with the Corpora Quadrigemina, and with the Cerebellum, and below with the anterior and lateral columns of the Spinal Cord.—The vesicular nucleus of each Olivary body, on the other hand, which is known from its peculiar shape as the *corpus dentatum*, has been thought to be especially connected with the origins of the nerves concerned in the movements of articulation; but though the Hypoglossal nerve passes directly through it, no connection has been traced between its ganglion-cells and the roots of that nerve, which pass backwards and inwards to a deeper centre. It is thought, on the other hand, by Mr. Lockhart Clarke, that the Olivary nuclei are co-ordinating centres for the different ganglia of the Medulla Oblongata; for, by a system of deep arciform fibres, a communication is established between the corpus dentatum of each side and the other parts of the Medulla, both on the same and on the opposite side.—The *Lateral* columns, which lie immediately behind the Olivary, are distinguished from them chiefly by the upward course of their fibres, which project, covered with grey substance, into the floor of the fourth ventricle, and then bifurcate, — one portion curving outwards to enter the peduncle of the Cerebellum, another ultimately reaching the motor tract of the Crus Cerebri, and the third forming a transverse commissure behind the Corpora Quadrigemina.

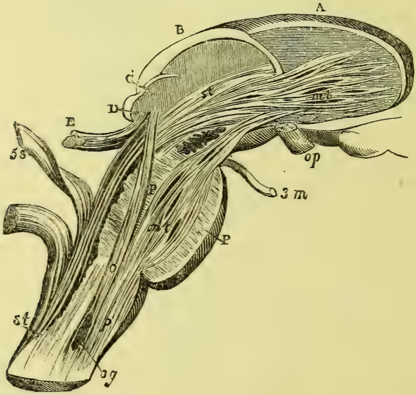
892. The fibres of the *Restiform* columns are continuous above with those of the hemispheres of the Cerebellum; and below they pass, without decussation, chiefly into the lateral portions, *o o*, Fig. 232, of the posterior columns of the Spinal Cord,—a band of *arciform* fibres, however, crossing-over to the anterior and lateral columns on each side. The grey nuclei of the restiform columns, which closely approximate those of the lower part of the posterior pyramidal, do not seem to give origin to any nerves.

893. The *Posterior Pyramids* are two small strands of fibrous structure, lying between the two restiform bodies, and occupying the portion of the Medulla Oblongata on either side of the posterior median furrow. They may be traced upwards into the Thalami Optici, and downwards into the median portions, *b b*, Fig. 232, of the posterior columns and the posterior part of the lateral.—The summits of the grey nuclei of the Posterior Pyramids, situated immediately beneath the fourth ventricle,

are the ganglionic centres of the Auditory nerves, or the proper *Auditory* ganglia.*

894. When we consider these various lines of communication simply in their Physiological relations, as establishing connections between the Encephalon above and the Spinal Cord below, it will be convenient first to notice and put aside the *Cerebellar*. Of these there are two sets; the principal forming the Restiform bodies, which connect the Cerebellum with the posterior columns of the Spinal cord; whilst there is another division, which comes into connection through the Olivary and Pyramidal bodies, with the anterior and antero-lateral columns.—The remaining fibres, which constitute what are improperly called the *Crura Cerebri*, may be considered as forming two principal tracts, the *sensory* and the *motor;* these being distinguished as such by the character of the nerves which arise in their course. The *sensory* tract (Fig. 235,

Fig. 235.



st) passes upwards from the posterior columns of the Spinal Cord, and the posterior part of the lateral, to the Thalami Optici (B); it seems continuous below with the tract in which the posterior

* The minute Anatomy of the Medulla Oblongata has been most elaborately treated by Mr. Lockhart Clarke, in the Philosophical Transactions for 1858.

† Dissection of the Medulla Oblongata, to show the connections of its several strands:—A, corpus striatum; B, thalamus opticus; C, D, corpora quadrigemina; E, commissure connecting them with the cerebellum; F, corpora restiformia; P, P, pons varolii; *st*, *st*, sensory tract; *mt*, *mt*, motor tract; *o*, olivary tract; *p*, pyramidal tract; *og*, olivary ganglion; *op*, optic nerve; 3*m*, root of the third pair (motor); 5*s*, sensory root of the fifth pair.

roots of the Spinal nerves terminate, and, in its upward course, it receives the large or sensory root (5*s*) of the Fifth pair. On the other hand, the *motor* tract (*mt*) may be regarded as descending from the Corpora Striata (A) and Tubercula Quadrigemina (C, D) into the anterior and antero-lateral columns of the Spinal Cord; in its course it gives-off the roots of all the motor nerves usually considered as cranial; and the greater part of its fibres undergo decussation below the Pons Varolii (P, P). — The functions of the Medulla Oblongata are, therefore, of a double character; to bring the higher parts of the Encephalon into connection with the Spinal Cord and its nerves; and to serve as a centre for the reflex movements performed through the nerves that issue from itself. In both respects it corresponds precisely with any segment of the proper Spinal Cord; and there is no reason to believe that it possesses any other or more special endowments. The importance, however, of the reflex acts of Respiration and Deglutition, of which it is the centre, causes this portion of the Medulla to be the one whose integrity is most essential to the preservation of life; and it *seems*, therefore, to possess a character more distinctive than it really has.

895. The chief *excitor* nerve of the *Respiratory* movements, as already stated (§§ 685—687) is the afferent portion of the Par Vagum; but the afferent portion of the Fifth pair is also a powerful excitor; and the afferent portions of all the Spinal nerves, conveying impressions from the general surface of the body, as well as of the Sympathetic nerves distributed on the walls of the blood-vessels, have a supplemental action of the same kind. — The chief *motor* nerves are the Phrenic and Intercostals; which, though issuing from the Cord further down, unquestionably receive their stimulus to action from the Medulla Oblongata. The motor portions of several other spinal nerves are also partly concerned; as are also the Facial nerve, the motor portion of the Par Vagum, and the Spinal Accessory. The ordinary movements of Respiration involve little action of any motor nerves but the phrenic and intercostal; and it is only when an excess of the stimulus (produced, for example, by too long a suspension of the aërating process) excites *extraordinary* movements, that the nerves last enumerated are called into action.

896. The acts of *Prehension* of food with the lips, and of *Mastication*, though usually effected by voluntary power in the adult, seem to be capable of taking-place as a part of the reflex operation of the Medulla Oblongata, in the Infant, as in the lower animals. This is particularly evident in the prehension of the nipple by the lips of the infant, and in the act of suction which the contact of that body (or of any resembling it) seems to excite. The experiments provided for us by nature, in the production of anencephalous monstrosities, fully prove that the integrity of the

nervous connection of the lips and respiratory organs with the Medulla Oblongata is alone sufficient for the performance of this action; and experiments upon young animals from which the brain has been removed, establish the same fact. Thus Mr. Grainger found that upon introducing his finger moistened with milk or with sugar and water between the lips of a puppy thus mutilated, the act of suction was excited; and not merely the act of suction itself, but other movements having a relation to it; for as the puppy lay on its side, sucking the finger, it pushed-out its feet, in the same manner as young pigs exert theirs in compressing the sow's dugs. This action seems akin to many of those by which the lower animals take-in their food; and we may thus recognize in the Medulla Oblongata a distinct centre of reflex action for the reception and deglutition of aliment, analogous to the *stomato-gastric* ganglia of Invertebrated animals (§ 863).

897. In the movements of *Deglutition*, which, as formerly explained (§ 453), are purely reflex, the chief *excitor* is undoubtedly the afferent portion of the Glosso-pharyngeal nerve. It is found that if the trunk of this nerve, or its pharyngeal (but not its lingual) branches, be pinched, pricked, or otherwise irritated, whilst still in connection with the Medulla Oblongata, the movements concerned in the act of swallowing are excited. The same occurs if, when the trunk of the Glosso-pharyngeal has been divided, the cut extremity in connection with the Medulla Oblongata be irritated; but little or no muscular contraction is produced by irritation of the separated extremity; whence it is apparent that the Glosso-pharyngeal has little or no direct motor power, but acts as an excitor. In this it appears to be assisted by the branches of the Fifth pair distributed upon the fauces; and probably, also, by the branches of the superior laryngeal distributed upon the pharynx. The motor influence which is generated in respondence to the stimulus thus conveyed, appears to act chiefly through the branches of the Par Vagum, which are distributed to most of the muscles concerned in swallowing; but the Facial, the Hypoglossal, the motor portion of the Fifth, and perhaps also the motor portions of some of the Cervical nerves, are also concerned in the movement, and can effect it, though with difficulty, after the pharyngeal branches of the Par Vagum have been divided.

898. In the propulsion of the food down the Œsophagus, to which the glosso-pharyngeal nerve does not extend, the muscular contraction, so far as it is of a reflex nature (§ 455), must depend upon the œsophageal branches of the Par Vagum alone; their afferent portion being the excitor, and their motor portion giving the requisite stimulus to the muscles. The same must be the case in regard to the muscular contractions of the cardiac and pyloric sphincters, and of the walls of the Stomach, so far as regards their dependence upon the nervous system at all; but the degree of this is doubtful.

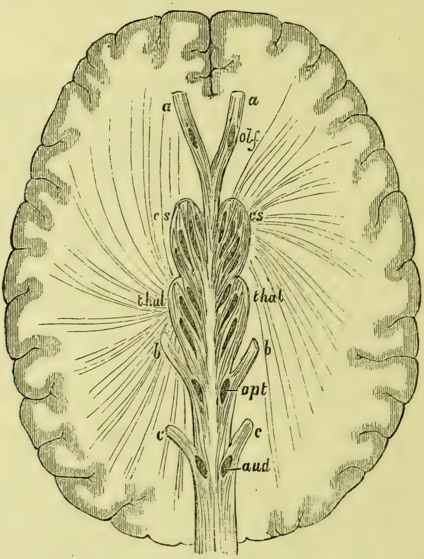
899. There are other reflex actions of the Medulla Oblongata, connected with the regulation of the aperture of the Glottis; these, which are effected through the superior and inferior laryngeal branches of the Par Vagum, will be better noticed when the actions of the Larynx come under consideration (§ 976).—In like manner, the reflex action concerned in the regulation of the aperture of the Pupil will be more conveniently noticed in the sketch to be hereafter given of the Physiology of Vision (§ 969).

5. *Functions of the Sensory Ganglia.*

900. All the nerves of sensation, both *general* and *special*, may be traced into a series of ganglionic masses lying at the base of the brain; which seem to constitute their own particular centres. Thus we have seen in Fishes the Olfactive, Optic, and Auditory ganglia marked-out as such by the termination of the nerves proceeding from the organs of smell, sight, and hearing, in these masses respectively. These ganglia bear an evident correspondence with the cephalic ganglia of the Invertebrata; which must chiefly, however, be regarded as *optic* ganglia, since the development of their eyes far surpasses that of the other organs of special sense. On the other hand, they find their representatives in certain organs at the base of the brain of Man and the higher Mammalia (Fig. 236); which, though small in proportion to the whole Encephalon, are capable of being clearly marked-out as the ganglionic centres of the several nerves of sense.—Thus, anteriorly, we have the *Olfactive* ganglia, in what are commonly termed the bulbous expansions of the Olfactive nerves; which, however, are real ganglia, containing grey or vesicular substance; and their separation from the general mass of the Encephalon, by the peduncles or footstalks commonly termed the trunks of the olfactory nerves, finds its analogy in several species of Fish (§ 869). The ganglionic nature of these masses is more evident in many of the lower Mammalia, in which the organ of smell is highly developed, than it is in Man, whose olfactive powers are comparatively moderate. —At some distance behind these we have the representatives of the *Optic* Ganglia, in the *Tubercula Quadrigemina*, to which the principal part of the roots of the Optic nerve may be traced. Although these bodies are so small in Man as to be apparently insignificant, yet they are relatively larger, and form a more evidently-important part of the Encephalon, in several of the lower Mammalia; though still presenting the same general aspect.—The *Auditory* ganglia seldom form distinct lobes or projections; but are usually lodged in the substance of the Medulla Oblongata. Their real character is most evident in certain Fishes, as the carp, in which we find the Auditory nerve having as distinct a ganglionic centre as the Optic. In higher animals, however, we are able to trace the Auditory

nerve into a small nucleus of grey matter which lies on each side beneath the Fourth Ventricle (§ 893); and although this is lodged in the midst of parts whose function is altogether different, yet there seems no reason for doubting that it has a character of its own, and that it is really the ganglion of the auditory nerve.—We are

Fig. 236.*



not able to fix upon any such mass of grey matter as the distinc *Gustatory* ganglion; nor is it necessary to attempt to do so, for as we shall see hereafter, we may regard the sense of Taste as a modification of that of Touch.

901. At the base of the Cerebral Hemispheres, we find tw ganglionic masses on either side, through which all the fibres pas

* Diagram of the relation of the Sensori-motor tract at the base of th Brain, to the Cerebrum, as seen in horizontal section :—*olf*, olfactive gang lia; *opt*, optic ganglia; *aud*, auditory ganglia; *cs*, corpora striata; *thal*, thalam optici; *a. a*, olfactive nerves; *b, b*, optic nerves; *c, c*, auditory nerves.—See also Fig. 237, *p.* 673.

that connect the Hemispheres with the Medulla Oblongata. These are the *Corpora Striata*, and *Thalami Optici.* Upon tracing forwards the tract of motor fibres that ascend from the Anterior Pyramids, we find it passing chiefly into the Corpora Striata; whilst if we follow the Sensory column that ascends from the Posterior Pyramids, we shall find it to enter the Thalami Optici. These bodies have been usually considered as mere appendages to the Cerebrum; but the fact that they are independent centres of action is fully established by the presence of a large quantity of vesicular matter in their substance; and there is now a sufficient amount of evidence, both anatomical and physiological, to render it probable that the fibres which seem to pass through them from the Crura Cerebri, and then to radiate towards the periphery of the Cerebral Hemispheres, do not do so in reality; but that these ganglionic masses receive, on the one hand, the fibres that ascend to them from the Medulla Oblongata, and, on the other, are the point of departure of a new set that passes to the proper Cerebrum. Looking to the connection of the Thalami Optici with the sensory tract, they may be not improbably considered as the ganglionic centres of *common* sensation; standing in the same relation to the sensory nerves that converge from various parts of the body towards the Encephalon, as do the Optic and other ganglia to their nerves of *special* sensation. And as these last give origin to motor fibres, so may we regard the ganglionic matter of the Corpora Striata (which are in close connection with the Thalami) as probably sharing in the same function; giving origin to the motor fibres which produce the respondent consensual movements, just as the anterior peak of grey matter in the Spinal Cord gives origin to the motor filaments which effect the reflex movements excited through the afferent fibres of the posterior roots.

902. The functions of this series of ganglia may be more certainly determined by the aid of Comparative Anatomy, than by experimental mutilations. Reverting to the class of Fishes, we find that it there constitutes (with the Cerebellum) nearly the entire Encephalon; scarcely a rudiment of the true Cerebrum being discoverable in that group.* And when we descend to the Invertebrata, we find the cephalic masses entirely to consist of the ganglionic centres of the nerves of sense and motion. There can scarcely be a reasonable doubt that these Cephalic ganglia are the seat of consciousness, and the sources of those movements which are directed by sensation, in such animals as present this low type of nervous organization; and there is no adequate reason for the belief, that the superaddition of the Cerebral Hemispheres in the

* The ganglionic masses that are commonly designated as the *Cerebral* lobes or hemispheres, must be really likened in great part (as already stated § 869) to the Corpora Striata.

Vertebrated series *alters* the endowments of the Sensory Ganglia on which they are superimposed; on the contrary, we everywhere see that the addition of new ganglionic centres, as instruments of new functions, leaves those which were previously existing in the discharge of their original duties. Hence we should be led to regard them as the centres of consciousness, even in Man, each pair of ganglionic centres ministering to that peculiar kind of sensation for which its nerves and the organs they supply are set apart; thus we should consider the Optic ganglia to be the seat of visual sensations, the Auditory to be the seat of the sense of hearing, and so on. And we should also consider them as the instruments whereby sensations, of whatever kind, either originate or direct *Automatic* movements.

903. So far as the results of experiments can be relied-on, they afford a confirmation of these views, by showing that the sensory impressions can be felt, and that automatic movements of a higher kind than the simply-reflex can be called into play, after the removal of the Cerebral Hemispheres, provided that these ganglia be left intact. Thus if a Bird be thus mutilated, it maintains its equilibrium, and recovers it when it has been disturbed; if pushed, it walks; if thrown into the air, it flies. A pigeon deprived of its cerebrum has been observed to seek-out the light parts of a partially illuminated room in which it was confined, and to avoid objects that lay in its way; and at night, when sleeping with closed eyes and its head under its wing, it raised its head and opened its eyes upon the slightest noise.—So, again, the removal or destruction of one pair of these Sensory centres appears to involve the loss of the particular sense to which it ministers; and frequently, also, to occasion such a disturbance in the ordinary movements of the animal, as shows the importance of these centres in regulating them. Such experiments have been chiefly made upon the *Optic* ganglia, or Corpora Quadrigemina; the partial loss of which on one side produces temporary blindness in the eye of the opposite side, and partial loss of muscular power on the opposite side of the body; whilst the removal of a larger portion, or the complete extirpation of it, occasions permanent blindness and immobility of the pupil, and temporary muscular weakness, on the opposite side. This temporary disorder of the muscular system sometimes manifests itself in a tendency to move on the axis, as if the animal were giddy; and sometimes in irregular convulsive movements.—Here, then, we have proof of the necessity of the integrity of this ganglionic centre, for the possession of the sense of vision; and we have further proof that the ganglion is connected with the muscular apparatus by motor fibres issuing from it. The reason why the eye of the *opposite* side is affected, is to be found in the *decussation* of the Optic nerves, a point to be immediately adverted-to (§ 907).

The influence of the operation on the muscles of the *opposite* side of the body, is at once understood from the fact of the decussation of the motor fibres in the anterior pyramids (§ 890).—Similar disturbances of movement have been produced by injuries to the organs of sense themselves, or to the nerves connecting them with the sensorial centres. Thus if one of the eyes of a pigeon be blindfolded, or its humours be evacuated, vertiginous motions ensue; and section of one of the semicircular canals of the ear in pigeons and rabbits has been found to occasion constant efforts to move in the plane of that canal, thus confirming the belief that the function of these canals is to indicate the direction of sounds (§ 952).

904. Notwithstanding that, in Man, the high development of *Intelligence*, and the exercise of the *Will*, supersede in great degree the operations of *Instinct*, we still find that there are in ourselves certain movements which can be distinguished as neither voluntary nor excito-motor, and which are examples of the method of operation that seems to be the chief source of the actions of the lower Vertebrata, as of the Invertebrate classes in general. These movements are as automatic and involuntary as are the ordinary reflex actions, but differ from them in requiring that the impressions which originate them should be *felt* as sensations; and hence they may be conveniently designated *sensori-motor* or *consensual*.—As examples of this group, we may advert to the start upon a loud and unexpected sound; the sudden closure of the eyes to a dazzling light, or on the approach of bodies that might injure them, which has been observed to take-place even in cases in which the eyelids could not be voluntarily closed; the act of sneezing excited by an irritation of the nostril, and sometimes also by a dazzling light; the semi-convulsive movements and the laughter called forth by tickling; and the vomiting occasioned by the sight or the smell of a loathsome object. So, again, the act of Yawning is ordinarily called-forth by certain uneasy sensations within ourselves, but also by the sight or hearing of the act as performed by another. Various phenomena of disease exhibit the powerful influence of sensations in producing automatic motions; as instances of this kind, we may refer to the effects of the sight or the sound of liquids, or of the slightest currents of air, in exciting the Hydrophobic paroxysm; whilst in many Hysteric subjects the sight of a paroxysm in another individual is the most certain means of its induction in themselves.—The most remarkable examples, however, of automatic movements depending upon sensations, are those which we come to perform *habitually*, and as we commonly say *mechanically*, when the attention and the voluntary effort are directed in quite a different channel. Thus the man who is walking through the streets in a complete reverie, unravelling some knotty subject, or

working-out a mathematical problem, not only performs the movements of progression (which may be excito-motor, § 885) with great regularity, but also directs these in a manner which plainly indicates the guidance of sensations. For he will avoid obstacles in the line of his path, and he will follow the course which he has been accustomed to take, although he may have intended to pass along some very different route; and it is not until his attention is recalled to his situation, that his train of thought suffers the least intermission, so that his Will is brought to bear upon his motions.

905. We may trace the agency of the Sensory Ganglia, however, in the Human subject, not merely in their direct and independent operation upon the muscular system, but also in the manner in which they participate in all Voluntary actions. The existence of a Sensation of some kind, in connection with Muscular exertion, seems essential to the continuance of the latter. Our ordinary movements are guided by what is termed the *Muscular Sense;* that is, by a feeling of the condition of the muscles, that comes to us through their own sensory nerves. How necessary this is to the exercise of muscular power, may be best judged-of from cases in which it has been lost. Thus a woman who had suffered complete loss of sensation in one arm, but who retained its motor power, found that she could not support her infant upon it without constantly *looking* at the child; and that if she were to remove her eyes for a moment, the child would fall, in spite of her knowledge that her infant was resting upon her arm, and of her desire to sustain it. Here, the muscular sense being entirely deficient, the sense of Vision supplied what was required so long as it was exercised upon the object; but as soon as this guiding influence was withdrawn, the strongest Will could not sustain the muscular contraction.—Again, in the production of vocal sounds, the nice adjustment of the muscles of the Larynx, which is requisite to produce determinate tones, can only be effected in obedience to a mental conception of the tone to be uttered; and this conception cannot be formed unless the sense of hearing has previously brought similar tones to the mind. Hence it is that persons who are born *deaf* are also *dumb*. They may have no malformation of the organs of speech; but they are incapable of uttering distinct vocal sounds or musical tones, because they have not the guiding conception or recalled sensation of the nature of these. By long training, and by efforts directed by the muscular sense of the larynx itself, some persons thus circumstanced have acquired the power of speech; but the want of sufficiently-definite control over the vocal muscles is always very evident in their use of the organ. — It will be shown hereafter (§ 968) how simply all the combinations of diverse muscular actions which take place in the conjoint movements of the

Eyeballs may be explained on the doctrine of the guidance of sensations in carrying into effect the mandates of the Will (§ 923).

906. Quitting now the functions of the Sensory Ganglia, we have briefly to notice certain peculiarities in the characters of the Nerves to which they serve as the centres. And of these peculiarities, there is one of a very remarkable nature, which is common to the three nerves of *special* sense, — namely, the Olfactive, Optic, and Auditory;—that they are not in the least degree endowed with *common* sensibility; so that they may be cut, stretched, pinched, &c., without producing the least pain. Hence the ordinary sensibility of the surfaces they supply is entirely due to the branches of the Fifth pair which are distributed upon them; and we may have a loss of either the *general* or the *special* sensibility of any of the organs of sense, without the other being affected, save indirectly.—Again, we do not find that irritation of these nerves produces any other purely *reflex* movements, than such as are connected with the operations of the organs of sense in which they respectively originate. Thus the Olfactory nerve cannot, by any irritation, be made to excite a reflex movement; the only reflex action that can be excited by irritating the Optic nerve, is contraction of the Pupil; and the regulation of the tension of the Membrana Tympani (if, as is probable, this be effected by the motor power of the Facial nerve, excited by impressions made upon the organ of sense) appears to be the only reflex action to which the Auditory nerve can minister.

907. There is a further peculiarity of a very marked kind attending the course of the *Optic* nerves: this is the crossing or decussation which they undergo, more or less completely, whilst proceeding from their ganglia to the eyes. In some of the lower animals, in which the two eyes (from their lateral position) have entirely different spheres of vision, the decussation is complete; the whole of the fibres from the right Optic ganglion passing into the left eye, and *vice versâ*. This is the case, for example, with most of the Osseous Fishes (as the cod, halibut, &c.); and also, in great part at least, with Birds. In the Human subject, however, and in animals which, like him, have the two eyes looking in the same direction, the decussation seems less complete; but there is a very remarkable arrangement of the fibres, which seems destined to bring the two eyes into peculiarly consentaneous action. The *posterior* border of the Optic Chiasma is formed exclusively of *commissural* fibres, which pass from one *optic ganglion* to the other, without entering the real optic nerve. Again, the *anterior* border of the chiasma is composed of fibres, which seem, in like manner, to act as a commissure between the two *retinæ;* passing from one to the other, without any connection with the optic

ganglia. The tract which lies between the two borders, and occupies the *middle* of the chiasma, is the true optic nerve; and in this it would appear that a portion of the fibres decussates, while another portion passes directly from each Optic ganglion into the corresponding eye. The fibres which proceed from the ganglia to the retinæ, and constitute the proper optic nerves, may be distinguished into an internal and external tract. Of these, the *external*, on each side, passes directly onwards to the eye of *that* side; whilst the internal crosses over to the eye of the *opposite* side. The distribution of these two sets of fibres in the retina of each eye respectively, is such that, according to Mr. Mayo, the fibres from either optic ganglion will be distributed to *its own side* of *both* eyes;—the right optic ganglion being thus exclusively connected with the outer part of the retina of the right eye, and with the inner part of the retina of the left eye; and the left optic ganglion being, in like manner, connected exclusively with the outer side of the left retina, and with the inner side of the right. Now as either side of the eye receives the images of objects which are on the other side of its axis, it follows, if this account of their distribution be correct, that in Man, as in the lower animals, each ganglion receives the sensations of objects situated on the *opposite* side of the body; and there is evidence both of a Physiological and of a Pathological character, that such is really the case. The purpose of this decussation may be to bring the Visual impressions, which are so important in directing the movements of the body, into proper harmony with the Motor apparatus; so that, the decussation of the motor fibres in the pyramids being accompanied by a decussation of the optic nerves, the same effect is produced as if neither decussated,—which last is the case with Invertebrated animals in general.

6. *Functions of the Cerebellum.*

908. Much discussion has taken-place, of late years, respecting the uses of the Cerebellum; and many experiments have been made to determine them. That it is in some way connected with the powers of *motion*, might be inferred from its connection with the antero-lateral columns of the Spinal Cord, as well as with the posterior; and the comparative size of the organ, in different orders of Vertebrated animals, gives us some indication of what the nature of its function may be. For we find its degree of development to correspond pretty closely with the variety and energy of the muscular movements which are habitually executed by the species; the organ being the largest in those animals which require the *combined* effort of a great variety of muscles

to maintain their usual position, or to execute their ordinary movements; whilst it is the smallest in those which require no muscular exertion for the one purpose, and little combination of different actions for the other. Thus in animals that habitually rest and move upon four legs, there is comparatively little occasion for any organ to combine and harmonize the actions of their several muscles; and in these the Cerebellum is usually small. But among the more active predaceous Fishes (as the Shark), Birds of the most powerful and varied flight (as the Swallow), and such Mammals as can maintain the erect position, and can use their extremities for other purposes than support and motion,—we find the Cerebellum of much greater size, relatively to the remainder of the Encephalon. There is a marked advance in this respect as we ascend through the series of Quadrumanous animals, from the Baboons which usually walk on all-fours, to the semi-erect Apes which often stand and move on their hind-legs only. The greatest development of the Cerebellum is found in Man; who surpasses all other animals in the number and variety of the combinations of muscular movement which his ordinary actions involve, as well as of those which he is capable of learning by practice to execute.

909. From experiments upon all classes of Vertebrated animals, it has been found that, when the Cerebellum is removed, the power of walking, springing, flying, standing, or maintaining the equilibrium of the body is destroyed. It does not seem that the animal has in any degree lost the *voluntary* power over its individual muscles; but it cannot *combine* their actions for any general movements of the body. The *reflex* movements, such as those of respiration, remain unimpared. When an animal thus mutilated is laid on its back, it cannot recover its former posture; but it moves its limbs, or flutters its wings, and evidently is not in a state of stupor. When placed in the erect position, it staggers and falls like a drunken man; not, however, without making efforts to maintain its balance. Phrenologists, who attribute a different function to the Cerebellum, have attempted to put aside these results, on the ground that the severity of the operation is alone sufficient to produce them; but, as we have already seen (§ 903), many animals may be subjected to a much more severe operation, the removal of the Cerebral hemispheres, without the loss of the power of combining and harmonizing the muscular actions, provided the Cerebellum be left uninjured. Partial removal of the Cerebellum produces the same effect for a time; but it has been found by Dr. Dalton that if the animal can be kept alive for some days, the co-ordinating power is in great degree recovered. The idea of the functions of the Cerebellum which we thus derive from Comparative Anatomy and from the results of experiment, is also consistent with inferences

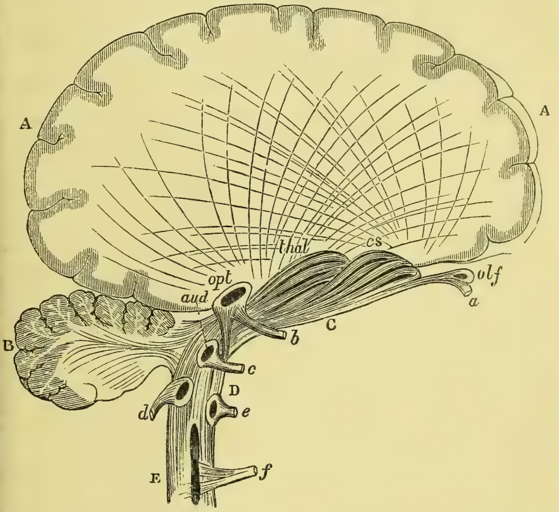
was produced, even though the mind was perfectly clear at the time. Hence it would appear that neither is the Cerebrum itself the centre of sensation, nor is it so connected with that centre, as to be able to convey to it sensory impressions of an *ordinary* kind. This is analogous to the condition of the nerves of *special sense*, as already remarked. That no irritation of the cerebral substance should excite convulsive movements, is a very remarkable circumstance; and it seems to indicate that the changes which *mental* operations produce in the cerebral fibres cannot be imitated, as changes in other motor fibres may be, by physical impressions.

913. As already stated, the relative amount of *Intelligence* in different animals bears so close a correspondence with the relative size and development of the Cerebral Hemispheres, that it can scarcely be questioned that these constitute the organ of the reasoning faculties, and issue the mandates by which the Will calls the muscles into action. It must be borne in mind, however, that *size* is not by any means the only indication of their comparative development. As we advance from the lower to the higher Vertebrata, we observe a marked advance in the *complexity of the structure* of the Cerebrum. Its surface becomes marked by convolutions, that greatly increase the area over which blood vessels can enter it from the surrounding membranes; and in proportion to the increase in the number and depth of these, do we find an increase in the thickness of the layer of *grey* matter, which is the source of all the powers of the organ. The arrangement of the white or fibrous tissue, which forms the interior of the mass, also increases in complexity; and as we ascend even from the lower Mammalia up to Man, we trace a marked increase in the number of the fibres which establish communications between different parts of the organ. It is, in fact, not merely from the different parts of the grey matter which forms the *surface* of the hemispheres, that these commissural fibres arise, but also from those isolated portions of vesicular substance which are found in different parts of their interior; and an extremely complex system is thus formed, which is still but very imperfectly understood.

914. The most important group of commissural fibres, is that which connects the *Sensory* with the *Hemispheric* Ganglia; that is, which radiates from the Thalami Optici (Fig. 237, *thal*), and Corpora Striata (*cs*) to the stratum of grey matter which forms the convoluted surface of the Cerebrum (*A*, *A*). These fibres constitute, in fact, the principal part of the white substance of the brain; the remainder being made-up by the commissures to be presently described, and by commissural fibres which (it is probable) connect the different parts of the Cerebral surface with each other. It was formerly supposed (and is still maintained by many Anatomists), that the radiating fibres which may be traced

from the surface of the Cerebrum to the Corpora Striata and Thalami Optici, *pass through* these bodies, so as to become continuous with the Crura Cerebri, and consequently with the sensory and motor tracts of the Medulla Oblongata. But when the small size of the Crura Cerebri is compared with the relatively enormous bulk of the radiating fibres, it is obvious that the former can only contain a very small proportion of the latter; and as no absolute continuity has been traced, it appears more

Fig. 237.*



conformable to Anatomical and Physiological probability, to believe that the fibres of the Crura Cerebri pass no further upwards than the Sensory Ganglia, and that the radiating fibres

* Diagram of the mutual relations of the principal Encephalic centres, as shown in a vertical section:—A, Cerebrum; B, Cerebellum; C, Sensori-motor tract, including the Olfactive ganglion *olf*, the Optic *opt*, and the Auditory *aud*, with the Thalami Optici *thal*, and the Corpora Striata *cs*; D, Medulla Oblongata; E, Spinal Cord;—*a*, olfactive nerve; *b*, optic; *c*, auditory; *d*, pneumogastric; *e*, hypoglossal; *f*, spinal; fibres of the medullary substance of the Cerebrum are shown, connecting its ganglionic surface with the sensori-motor tract.—See also Fig. 236, p. 662.

take a fresh departure from these bodies to pass towards the surface of the Cerebrum.—Thus, then, we should be led to regard the Spinal Cord, Medulla Oblongata, and chain of Sensory Ganglia, as precisely representing the entire Nervous System of Insects, the character of whose action is essentially *automatic*; and to consider the Cerebrum as an organ superadded to its summit, receiving all its incitement to action from impressions transmitted to it through the Sensory Ganglia, and carrying into effect its volitional determinations and its ideational and emotional impulses, not (as formerly supposed) by immediately exciting muscular movements through nervous communications passing direct from the convoluted surface of the Cerebrum, but by playing downwards upon the Automatic apparatus by which its mandates are carried into effect (Fig. 236, 237). Of this view we shall presently find that there is strong physiological evidence (§ 923).

915. The two Hemispheres are united on the median line by several *transverse* commissures; of which the *Corpus Callosum* is the most important. This consists of a mass of fibres very closely interlaced together; which may be traced into the substance of the hemispheres on each side, particularly at their lower part, where they are connected with the Thalami Optici and Corpora Striata. It is difficult, if not impossible, to trace its fibres any further; but there can be little doubt that they radiate, with the fibres proceeding from the bodies just named, to the different parts of the surface of the hemispheres. This commissure is altogether absent in Fish, Reptiles, and Birds; and it is partially or completely wanting in the Mammals with least perfect brain, as the Rodents and Marsupials.—The other transverse commissures rather belong to the Sensory Ganglia than to the Cerebral Hemispheres. Thus the *anterior* commissure particularly unites the Corpora Striata of the two sides; but many of its fibres pass through these organs, and radiate towards the convolutions of the hemispheres, especially those of the middle lobe. This commissure is particularly large in those Marsupials in which the corpus callosum is deficient.—The *posterior* commissure is a band of fibres which connects the Optic Thalami, crossing-over from the posterior extremity of one to that of the other.—Besides these, there are other groups of fibres which seem to have similar commissural functions, but which are intermingled with vesicular substance. Such are the *soft* commissure, which also extends between the thalami; the Pons Tarini, which extends between the two crura or peduncles of the Cerebrum; and the Tuber Cinereum, which seems to unite the optic tracts with the thalami, the corpus callosum, the fornix, &c., and to be a common point of meeting for several distinct groups of fibres.

916. The anterior and posterior parts of the Hemispheres, more-

over, are connected by *longitudinal* Commissures, of which some lie above, and some below, the corpus callosum; and of these, also, a part belong to the Sensory Ganglia. Above the transverse fibres of the corpus callosum, there is a longitudinal tract on each side of the median line, which serves to connect the convolutions of the anterior and posterior lobes of the brain.—And above this, again, is the *superior longitudinal commissure*, which is formed by the fibrous matter of the great convolution nearest the median plane on the upper surface of the brain, and which connects the convolutions of the anterior and middle lobe with those of the posterior.—Beneath the great transverse commissure, we find the most extensive of all the longitudinal commissures, namely, the *fornix.* This is connected in front with the optic thalami, the mammillary bodies, the tuber cinereum, &c.; and behind, it spreads its fibres over the hippocampi (major and minor), which are nothing else than peculiar convolutions that project into the posterior and descending cornua of the lateral ventricles.— The fourth longitudinal commissure is the *tænia semicircularis*, which forms part of the same system of fibres with the fornix; connecting the corpus mammillare and thalamus opticus of each side with the middle lobe of the cerebral hemisphere.—If, as Dr. Todd has remarked, we could take away the corpus callosum, the grey matter of the internal convolution, and the ventricular prominence of the optic thalami, then all these commissures would fall together, and become united as one and the same series of longitudinal fibres.— It is curious that there should be no direct communication between the Cerebral hemispheres and the Cerebellum; the only commissural band between them being the *processus a cerebello ad testes*, which passes onwards, through the tubercula quadrigemina, to the thalamus opticus on each side. This would seem to confirm the idea of the complete distinctness of their functions.

917. The Cerebrum appears to be the instrument of all those psychical operations, which are superadded, in Man and the higher Vertebrata, to mere sensations. The impressions which are merely *felt* in the sensorium, give rise, when they pass upwards into the Cerebrum, to *Ideas*, which then become the material (so to speak) of all the higher mental processes. These processes may be ranked under two distinct heads, namely, the *Emotional* and the *Intelligential;* the former being most intimately connected with the sensations which prompt them, whilst the latter are commonly of a much more abstract character. The Emotions may, in fact, be considered as *feelings*, often of mere pleasure or pain, associated with particular classes of ideas; and it is this association which gives them the character of the moving or active powers of the mind, and which makes them, either directly or indirectly, the springs of the greater part of our actions. Thus Benevolence is

the feeling of pleasure in the idea of the welfare and happiness of others; and Hope is the pleasurable contemplation of the idea of some anticipated good. When strongly excited, the Emotions may produce movements which the Will may not be able to restrain; as when we burst into laughter at some ludicrous image presented to the mind, either by a present sensation or by an act of the memory or imagination, notwithstanding the strongest inducements presented by 'time, place, and circumstance' to a preservation of our gravity. The distinctness of the character of Emotional and Volitional movements is further evident from this, that cases of paralysis not unfrequently occur (especially in the facial nerve, through which most of the muscles of 'expression' are excited to action), in which the muscles are obedient to one class of impulses, while the other exerts no power over them. Thus, in one instance, the muscles of one side of the face were palsied in such a manner that the patient could not voluntarily close his eye nor draw his mouth towards that side; yet when any ludicrous circumstance caused him to laugh, their usual play was manifested in the expression of his countenance. And in another case, the muscles were obedient to the Will; but when the individual laughed or cried under the influence of an emotion, it was only on one side of his face. To these may be added another case, in which the right arm was completely palsied, so that the individual had not the least voluntary power over it; yet it was violently agitated whenever he met a friend whom he desired to greet.—The influence of an undue tendency to Emotional excitement, is remarkably seen in what are ordinarily termed *Hysterical* states of the system; in which violent convulsive paroxysms are frequently brought-on by the most trivial causes, if these should call the passions or affections of the mind into undne activity. This condition is more frequently seen in the Female than in the Male, the Emotions being naturally more predominant in the former, the Intellect and Will in the latter; but it often supervenes in Men who have been characterized when in health by the most vigorous self-control (§ 922), when their Volitional power has been weakened by disease or exhaustion.—There can be no doubt that many of the peculiar actions performed by the subjects of what is termed *Mesmeric* influence, are the result of a condition of this nature. There appears to be, in such persons, a proneness to activity of the consensual and emotional parts of the nervous centres, which manifests itself most strongly when the control of the will is withdrawn; and thus very slight impressions produce very powerful involuntary movements,—especially when this response is favoured by the strong desire, on the part of the patient, to exhibit any particular manifestation that is known to be expected by the bystanders.

918. It has been supposed by some that the *Emotional* move-

ments of Man and the higher animals may be ranked in the same category with the *Instinctive* actions of the lower; and that the *Desires* of the former are comparable to the instinctive *Propensities* of the latter. But this comparison is erroneous; for what we term propensities (among the lower animals) are nothing else than tendencies to perform particular movements in respondence to particular sensations, without any *idea* of the purpose of the movement, or of the object which has excited it; whilst an Emotion involves an idea of the object which has called it up, and a Desire involves a conception of the object to be attained.— The *imitative* actions afford a good example of the difference between a propensity and a desire. The propensity to involuntary imitation, which is much stronger in some individuals than in others, is manifested in such imitative movements as are purely consensual; the sensation, which is the mainspring of the action in each case, exciting a respondent automatic movement, as when we yawn involuntarily from seeing or hearing the action performed by another, or as when children learn undesignedly to perform many of the movements which they witness in adults. On the other hand, imitative actions may be voluntarily performed as the result of a *desire* to execute them, which involves a distinct idea of the object; and the moving force of this desire is derived from the pleasure which the individual derives from the performance, and which he finds either in the act itself, or in the enjoyment which it affords to others, or in its prospective benefits to himself. Thus we see that the Mind (properly so called) is concerned in all Emotional actions; whilst there is no evidence of the participation of any higher attribute than Sensation in the purely Instinctive acts; and even this is not a requisite link in the chain by which many of those movements are excited, that are usually grouped together under that designation.

919. Again, the Emotions may be excited by operations of the Mind itself, as well as by sensations immediately received from without. Thus, involuntary laughter may result from a ludicrous idea, called-up by some train of association, and having no obvious connection with the sensation which first set this process in operation; and the various movements of the face and person by which Actors endeavour to express strong emotions, are most effectual in conveying their meaning, when they result from the actual working of the emotions in the mind of the performer, who has, by a voluntary effort, identified himself (so to speak) with the character he personates. A still more remarkable case is that in which paroxysms of Hysterical convulsions, in themselves beyond the power of the Will to excite or to control, are brought-on by a voluntary effort; this being exerted, not in the attempt to perform the movements, but in 'getting-up' (so to speak) the state of feeling, from which, when it is once excited,

the movements spontaneously flow. In all these instances, and others of like nature, it would seem as if the agency of the Cerebrum produced the same condition in the Automatic centres, as that which is more directly excited by sensations received through their own afferent nerves.—But on the other hand, the Emotions, by their influence on the Reasoning processes, are largely concerned in many actions which are strictly voluntary. In fact, it may be questioned whether there are *any* of our actions, the *power* necessary for the performance of which is not derived, directly or indirectly, from emotional states of mind; for our *motives* to any kind of exertion are found, if carefully analysed, to consist in great part in the anticipation of pleasure to be derived or pain to be avoided, either in the performance of the action, or in the consequences which our reasoning processes connect with it. And it will be found that the difference between those persons who are said to act from *feeling*, and those who are said to be guided by *reason*, is not precisely what these terms imply; for the actions of both are equally determined by the motives supplied by emotional states; and the difference rather lies in this, that one class act on their *first* impulses without considering the consequences, whilst the other calculate the *remoter* results, and weigh the future pain against the present pleasure, the ultimate enjoyment against the immediate distress.—The Emotional states are peculiarly liable to be influenced by the condition of the corporeal system; thus a very slight depravation of the blood may produce an irresistible tendency to take a gloomy view of everything to which the mind may be directed, and especially of all that relates to the individual; whilst that condition of perfect health which is derived from wholesome recreation, fresh air, active exercise, &c., is almost always accompanied with a degree of cheerfulness and elasticity, which occasions even real evils to be but comparatively little felt.

920. When we turn our attention to the *Intelligential* actions, of which the Cerebrum appears (in our present state of being) to be the exclusive instrument, we perceive that the attribute by which they are distinguished both from the Instinctive and the Emotional, is their *intentional* or *purposive* performance, in accordance with the mental conception of the object to be attained, and the intellectual belief as to the most advantageous means of accomplishing it.—Now when we come to analyse the faculties concerned in this class of operations, we find that the one most closely related to the simple Sensorial powers already treated-of, and at the same time most essential to all the higher operations, is *Memory*. This faculty is one of those first awakened in the opening mind of the Infant; and we find traces of it in animals that seem to be otherwise guided by pure Instinct. It obviously affords the first step towards the exercise of the reasoning powers,

since no *experience* can be gained without it; and the foundation of all intelligent adaptation of means to ends, lies in the application of the knowledge which has been acquired and stored-up in the mind. There is strong reason to believe that this attribute belongs to the Cerebrum exclusively; no impressions made upon the Sensorial centres being ever remembered, unless they are registered (as it were) in this organ. And further, there is evidence that no impression of this kind once made upon the Cerebrum is ever entirely lost in the normal state; although disease or accident will sometimes occasion a complete destruction of the memory, or will obliterate the remembrance of a particular class of objects or of ideas. Memory, however, seems almost invariably to depend upon the principle of *Association* or *Suggestion;* one idea being linked with another, or with a particular sensation, in such a manner as to be called-up by its recurrence; and a period of many years frequently intervenes without that combination of circumstances presenting itself, which is requisite to arouse the dormant impression of some early event. Sometimes this combination occurs in Dreaming, Delirium, or Insanity, three states which agree in this, that the Will has no control over the current of thought; and ideas are thus recalled, of which the mind in a state of healthy activity has no remembrance.—It is upon the ideas aroused in the mind by Sensorial changes, or recalled by *Conception*, or evolved by the process of *Reflection* (in which the mind perceives its own operations, and traces relations amongst its objects of thought), or generated by the *Imagination* (which really acts, however, rather by making new combinations, than by creating altogether *de novo*), that all acts of *Reasoning* are based. These consist, for the most part, in the aggregation and collocation of ideas, the decomposition of complex ideas into more simple ones, and the combination of simple ideas into general expressions: in which are exercised the faculty of *Comparison*, by which the relations and connections of ideas are perceived; that of *Abstraction*, by which we fix our attention on any particular qualities of the object of our thought, and isolate it from the rest; and that of *Generalization*, by which we form some definite apprehensions in regard to the general relations of those objects. These are the processes chiefly concerned in the simple acquirement of Knowledge, with which class of operations the Emotional part of our nature has very little participation, save as furnishing the *desire* which may be the necessary incitement in the exertion of the intellect. But in the direction of our conduct in life, as just now shown, the Emotions have the principal share; since they afford some of the principal motives, either immediate or remote, by which our decisions are guided. In proportion, however, as the Moral Sense, or the estimate of an action according to the standard of *right* and

wrong, has been developed, and as its dictates are habitually attended-to, will it acquire a predominance over other motives, and become the guiding principle in every contingency in which it can properly be brought to bear.

921. Now the Mind, when not engrossed in taking cognizance of outward objects, is incessantly occupied in *thinking*, with or without the accompaniment of *feeling ;* its whole inner life being *a succession of Ideas and Emotions*, only suspended by Sleep and Death. A certain measure of mental activity seems natural to Man, provided that the development of his powers has taken-place under favourable circumstances ; and some of his highest pleasures are derived from the healthful and almost spontaneous exercise of its faculties. Now there is no doubt in the mind of any intelligent Psychologist, that the succession of mental states is essentially dependent on two sets of conditions :—namely, first, the succession of external impressions fitted to excite various kinds of mental action ; and, second, the mental constitution of the individual. This mental constitution depends in a great degree upon the original condition of the bodily organism, and upon the circumstances in which the individual has been placed ; which influences concur to establish certain *tendencies to thought and feeling*, which manifest themselves alike in the ordinary course of conduct, and in the more express products of the mental labour of the individual. Now in so far as the succession of our thoughts takes-place in accordance with the *habitudes* which are thus determined, may we consider that our character is formed *for* us, rather than *by* us ; and we may look upon our Mental activity, whether it manifest itself in the form of Thought or of Feeling, as no less *automatic* than the instinctive operations of the lower animals, though far more elevated in its nature. There can be no reasonable doubt that a large proportion of our ordinary Mental life is of this character ; the current of thought often flowing-on continuously without any interference on the part of the Will, just as our limbs continue to execute their habitual succession of movements in the act of walking, whilst the volitional direction is completely drawn-off from them. Many muscular actions, too, are the expression of the ideas which have for a time possession of the mind, as we most characteristically see in the states of Reverie, Somnambulism, Electro-Biology, &c., in which the Will is in temporary abeyance ; such movements may be appropriately designated *Ideo-motor*, and may be considered as the expressions of a 'reflex action' of the Cerebrum.

922. But the Will possesses a certain determining power over the mental as over the bodily operations ; and it is, in fact, this determining power which is the source of the *self-control* that characterizes the well-regulated mind of Man, and distinguishes him alike from the madman and the brute, giving him to a great

extent the power of forming his character and determining his actions *for himself.* The regulation of our conduct consists in the application of our reasoning powers to the circumstances of our condition, and in the maintenance of a due balance among those emotional tendencies which are the moving springs of our actions. However powerful these tendencies may be, there can be no doubt that we possess within ourselves the means of checking them, by withdrawing our minds by a voluntary effort from the thoughts which they suggest, as well as by calling-forth opposing influences within us; so that the decision which is finally arrived-at may be something very different from that which the first 'balance of motives' would have produced.—It is the deficiency or entire loss of this power of self-control, which usually constitutes the first step in the development of *Insanity ;* for this state generally consists, not so much in a perversion of the reasoning processes, as in a disorder of the emotional state, which causes the patient to dwell upon particular trains of thought until his feelings in relation to them become exaggerated or perverted; and at last intellectual delusions arise from the habit of viewing everything that comes before the mind through a distorted medium, and from the substitution of the patient's morbid imaginings for real occurrences. In the purely *impulsive* form of Insanity, there is no intellectual perversion ; but a desire of some kind is so powerfully excited, that the Will cannot control it. And every phase may be witnessed, between a state of this kind which renders the individual an irresponsible agent, and that mental condition in which the individual, though originally fully able to control himself, habitually gives way to his passions, and thus, by their continual indulgence, at last allows them to become the dominant powers of his mind.

923. Although the Will has been commonly regarded as *directly determining* those muscular movements which are usually distinguished as Voluntary, through the intermediation of fibres originating in the Cerebral convolutions and proceeding to the muscles, yet a careful analysis of the process fully bears out the idea already put forward, that the Will really operates through the Automatic apparatus, exciting particular groups of muscular actions, just as they would be called-forth by sensations directly excited by external objects. For it has been shown that the *Cranio-spinal Axis* (consisting of the Sensory Ganglia, Medulla Oblongata, and Spinal Cord) receives all the sensory nerves, and gives origin to all the motor; and that the fibres which pass between the Cerebral convolutions and the Sensory Ganglia, probably serve to bring these centres into mutual relation, and are not continuous with those of any nerves, either sensory or motor (§ 914). And we might expect, therefore, that the addition of a Cerebrum to this automatic apparatus would have the effect of

supplying a new stimulus to movement, which, whilst proceeding from mental operations, should still act through the same mechanism as that already provided for the Spinal and Consensual movements. Now when we attentively consider the nature of what we are accustomed to call *voluntary* action, we perceive that the agency of the Will is limited to the *determination of the result;* and that it has nothing to do with the selection and co-ordination of the individual movements by which that result is brought about. This is particularly obvious in the movements of the Eyes (§ 968) and of the Larynx (§ 905); but these only differ from ordinary voluntary movements in the speciality of the Sensations under whose guidance they are performed. If it were otherwise, indeed, we should be dependent upon our anatomical knowledge for our power of performing even the simplest movements of the body. Again, there are very few cases in which we can single out any individual muscle, and put it into action independently of others; and the cases in which we *can* do so are those in which a single muscle is concerned in producing the result, as in the elevation of the eyelid; and we then really single-out the muscle by 'willing' the result. Thus, then, however startling the position may at first appear, we have a right to affirm that the Will cannot exert any direct or immediate power over the muscles; but that its determinations are carried into effect through an intermediate mechanism, which, without any further guidance on our own part, selects and combines the particular muscles whose contractions are requisite to produce the desired movement. We have seen that the Sensorial centres play (so to speak) upon the Cerebrum, sending to it impressions of a kind fitted to call-forth its peculiar activity as an instrument of purely mental operations; and in return, the Cerebrum appears to play downwards upon the motor portion of the automatic apparatus, sending to it volitional impulses which excite its motorial activity. And thus we see that the very same action may be excited by an impression conveyed to the centres of the whole system through some one or more nerves of the *external senses*, or through the fibres converging to them from the cerebral convolutions, which have been not unaptly called 'the nerves of the *internal senses*'; and may hence be *automatic* in the first case, and *volitional* in the second. For example, in the act of Coughing, we have the very same combination and succession of diverse but mutually-related actions, whether the operation be excited by the presence of an irritating particle in the air-passages, or be performed as the consequence of a voluntary effort. And a little attention to his own consciousness will satisfy the reader, that, as regards the selection and coördination of the movements which are called-forth, the Intelligence and Will are no more concerned in the one case than in the other.—Hence it follows that all the movements which are

performed by the instrumentality of the Cerebro-Spinal system of ganglia and nerves, are in their essential nature *automatic ;* and that their character as Reflex, Instinctive, Emotional, or Voluntary, is entirely dependent on the nature and seat of the impulses which respectively originate them.

924. There are various conditions, some of them natural, others morbid, in which the distinctness of the functions of the Cerebral Hemispheres is well marked. Thus in profound Sleep they seem to be entirely dormant; the Spinal Cord and Medulla Oblongata, by which the necessary *reflex* actions are carried-on, being alone in a state of activity. In this condition the Sensory ganglia also appear to be in a torpid state; but in less profound sleep, actions are often performed which may be referred to the *consensual* group,—being such as the sensation would immediately prompt without any reflection, and not being remembered in the waking state. Thus we turn in our beds under the influence of an uneasy sensation; or we give some sign of recognition when our names are called. The first of these appears to be a purely consensual movement, being as *automatic* as if it were a reflex action; the other seems to have *become* as automatic by the influence of habit, and to belong to that class of *secondarily-automatic* actions, in which the movement, though at first directed by the will, has become, after very frequent performance, so closely associated with the guiding suggestion, as to be called-forth by it alone (§ 904).—In the Coma of apoplexy, narcotic poisoning, &c., we witness the same gradations as in ordinary sleep. When least profound it seems to affect the Cerebral hemispheres alone, the Sensory Ganglia being still in some degree open to the reception of impressions. When complete, however, none but reflex actions can be excited; and if it advance to a fatal termination, it does so by the supervention of the same state of torpidity in the Medulla Oblongata, whereby the respiratory movements are brought to a close. These movements do not cease until the power of deglutition has been lost, and until the eye ceases to close if the edge of the lid be irritated; but when this is the case a fatal termination may be apprehended, as it is thus shown that the torpor is extending to the Spinal system of nerves.—In the condition of Dreaming, it would seem as if the Cerebrum were *partially* active; a train of thought being suggested, frequently by sensations from without, which is carried on without any controlling or directing power on the part of the Will; and which is not corrected, or is only modified in a limited degree, by the knowledge acquired by experience. This condition is still more remarkable in Somnambulism, or (as it has been better termed) Sleep-waking; in which the dreams are not only *acted*, but may be often *acted-on* with the utmost facility,—a suggestion conveyed through any of the senses excepting sight (which is

usually in abeyance) being apprehended and followed-up with the utmost readiness, and, in like manner, with little or no correction from experience. Between this condition and that of ordinary dreaming, on the one hand, and that of complete insensibility on the other, every shade of variety is presented by different individuals, or by the same individual at different times. The Cerebellum, in the Sleep-walking state, seems to be frequently in a condition of peculiar activity; a remarkable power of balancing and combining the movements of the body being often exhibited.

925. On the other hand, there may be an undue exaltation or a perversion of Mental activity, without any affection of the sensorial apparatus. This is well seen, for example, in the first stage of Alcoholic excitement, and in that of Mania, Phrenitis, and other disorders in which the Cerebral Hemispheres are especially affected. Frequently, as in the case of Alcohol, Opium, Haschish, &c., we may directly attribute the morbid action of the Cerebrum to the presence of a poison in the blood which permeates it; and there is strong reason to believe that many other forms of Delirium are partly due to a perverted state of that fluid. On the other hand, there can be no doubt that an extreme reduction of Intellectual power, as well as depression of the Emotional state, is often to be attributed to a depravation of the blood; a slight accumulation of bile being very prone to occasion this state in some individuals, and an entire change being effected by a mild dose of a mercurial preparation, which, by eliminating the bile, restores the circulating fluid to its proper purity. And it may be fairly suspected that the foul atmosphere in the midst of which a large class of our population habitually lives, has the effect, by keeping their blood charged with noxious matters, of so perverting the actions of the brain, that neither the Intellectual powers nor the Moral sense can be duly exercised; and thus it may be anticipated that Sanitary Reform will largely benefit not merely the corporeal, but the mental and moral health, of many whose position is at present one of fearful degradation from the want of it.

8. *Functions of the Sympathetic System.*

926. Besides the Cerebro-Spinal apparatus, of which the several parts have now been described, another system of ganglia and nerve-trunks exists in the body of Man and the higher animals, which is characterized by the scattered and isolated positions of its centres, and by the peculiarity of the distribution of the trunks and branches proceeding from them. This *Sympathetic* system may be considered to include:—1. The ganglia and plexuses in immediate connection with the Viscera, viz., the *Cardiac*, the *Solar* (of which the principal centres are the *Semilunar* ganglia), and the *Hypogastric*. 2. The double chain of *Prevertebral*

ganglia, with connecting cords, which lies in front of the Vertebral column, and which communicates on the one hand with the Spinal nerves, and on the other with the plexuses just mentioned. Under this category we may rank the *ophthalmic*, *otic*, *spheno-palatine*, and *submaxillary* ganglia, which have the same kind of connection with the ordinary sensory and motor nerves of the head, that the prevertebral ganglia have with those of the trunk. 3. The *Spinal* ganglia on the posterior roots of the spinal nerves themselves; under which head are to be ranked the Gasserian ganglion of the Fifth pair, and the ganglia near the roots of the Pneumogastric and Glosso-pharyngeal nerves.—The trunks and branches proceeding from this system of ganglia are for the most distributed, not like those of the Cerebro-spinal system to the muscles and skin, but to the Visceral apparatus generally, most parts of which receive their nervous supply from it alone; and especially to the walls of the Blood-vessels, on which they form a plexus whose branches accompany their minutest ramifications. The Cranial ganglia seem to be in special relation, not merely with the vascular system of the parts to which their branches are distributed, but also with the deeper muscles whose actions relate to the *protection* of the organs of sense. Thus from the *Ophthalmic* ganglion proceed the nerves which call forth the contraction of the iris (§ 969); the *Otic* ganglion supplies the tensor tympani muscle, which seems to have a like regulative action on the tympanum (§ 951); and the *Spheno-palatine* ganglion supplies the levator palati and azygos uvulæ muscles, which tend to close the posterior nares. In all these instances the reflex action is excited by a sensation felt in the Cerebro-spinal centres, and the respondent motor impulse is transmitted in the first instance along an ordinary motor nerve; this nerve, however, does not proceed direct to the muscle, but enters the Sympathetic ganglion, and the movements it excites through the filaments proceeding from that ganglion partake of the tardiness which characterizes those excited through other parts of the Sympathetic system (§ 927), as we especially see in the case of the iris, which requires an appreciable time to adjust itself to a sudden change in the quantity of light.—The Sympathetic system contains both classes of nervous fibres: the ordinary *white tubular* fibres, all of which are probably derived from the Cerebro-Spinal system; and the *grey* or *gelatinous* fibres, the greater part of which seems to belong to itself. Thus we may consider each system as intermingling itself with the other: the Cerebro-Spinal system transmitting some of its fibres, both motor and sensory, into the Sympathetic; whilst the Sympathetic is represented in the Cerebro-Spinal system by the ganglia on the roots of the Spinal nerves, the fibres proceeding from which, reinforced with others derived from the Sympathetic system, are distributed with the branches of those nerves, their

ultimate destination (it would seem) being to the walls of the blood-vessels. The trunks that proceed from the Semilunar ganglia are in great part composed of gelatinous fibres; whence it is evident that these ganglia are to be regarded as the true centres of the Sympathetic system. On the other hand, the trunks which issue from the chain of Prevertebral ganglia contain a large admixture of white or tubular fibres.—The peculiar connection of this system of nerves with the Visceral apparatus, has caused it to receive the designation of the 'nervous system of organic life;' the Cerebro-Spinal system being termed the 'nervous system of animal life.' It is also not unfrequently termed the *ganglionic* system, on account of that separation of its centres into scattered ganglia, which forms a striking contrast to the concentration so evident in the Cerebro-Spinal system. But this term is objectionable, as leading to a supposed analogy between this system and the general nervous system of Invertebrata, whose centres are equally scattered;—an analogy which is completely erroneous, since, as we have seen, this last is chiefly the representative of the Cerebro-Spinal system of Vertebrate animals. The term *Sympathetic* is perhaps the best; although it must not be supposed that this system of nerves is the instrument of by any means *all* the sympathies which manifest themselves between different organs.

927. The nerves of the Sympathetic system possess a certain degree of power of exciting Muscular contractions in the various parts to which they are distributed; these contractions, however, do not follow directly upon the application of the stimulus, but take place in a kind of hesitating uncertain manner. By irritating these nerves immediately after the death of an animal, contractions may be excited in any part of the alimentary canal from the pharynx to the rectum, according to the trunks which are irritated, — in the heart, after its ordinary movements have ceased, — in the aorta, vena cava, and thoracic duct, — in the ductus choledochus, uterus, fallopian tubes, vas deferens, and vesiculæ seminales. But as the very same contractions may be excited by irritating the roots of those Spinal nerves from which the Sympathetic trunks receive their white fibres, there is strong reason to believe that the *motor* power of the latter is entirely dependent upon the Cerebro-spinal system, as is certainly the case with those proceeding from the Ophthalmic ganglion. Whatever *sensory* endowments the Sympathethic trunks possess, are probably to be referred to the same connection. In the ordinary condition of the body, these are not manifested; for the parts exclusively supplied by Sympathetic trunks do not appear to be in the least degree sensible, and no sign of pain is given when the Sympathetic trunks themselves are irritated. But in certain diseased conditions of those organs, violent pains are felt in them,

which can only be produced through the medium of fibres communicating with the sensorium through the Spinal nerves; and experiment shows that whilst slight impressions upon the nerves of these organs call-forth no indications of suffering, such indications are manifested when the impression is made stronger. Thus it would seem that the passage of the sensory nerves through the ganglia diminishes their power of conveying impressions to the Sensorium; not improbably because the effect of those impressions is ordinarily diffused by radiation through the Sympathetic system itself, and is exerted in calling-forth its own peculiar actions.—How far the ordinary movements of the Heart, Alimentary canal, &c., are *dependent* upon nervous influence, has been already considered (§§ 461, 580); but their independence does not prevent them from being greatly influenced, through their connections with the Sympathetic system, by states of mind (especially of an emotional character), and by impressions made on other organs (§ 581).

928. It is now well ascertained that one of the most important functions of the Sympathetic system is the regulation of the calibre of the Blood-vessels, by the influence of its nerves upon the muscular fibres contained in their walls (§ 586); and there is evidence that these *vaso-motor* nerves are distributed not merely through the Sympathetic system, but also through the Cerebro-spinal. When the Sympathetic nerve is divided in the neck of a Cat, Rabbit, or Pigeon, the blood-vessels of that side dilate; and with the larger current of blood which then flows through the capillaries, an exaltation takes place in the vital properties of all the tissues on the same side of the head. Thus the sensibility of the retina for light appears to be augmented, whence follow contraction of the pupil, retraction of the globe of the eye, partial closure of the eyelid, and projection of the *membrana nictitans* (where present), with increased flow of tears. The temperature of the surface is exalted, sometimes as much as 18°; and the sensibility and secretions of the skin are augmented. The muscles respond more readily to weak and more energetically to strong stimuli, and retain their irritability longer; and the nutritive processes seem to take place with greater activity. The vascular turgescence is especially marked in the lining membrane of the ear of the Cat or Rabbit. When, on the other hand, the upper cut extremity of the nerve is galvanized, all these effects are reversed; the vascular turgescence disappears, the pupil dilates, the eyelid is widely opened, the temperature and sensibility of the parts decrease, and the contractile power of the muscles diminishes. Corresponding effects have been produced on the lower extremities by destruction of the lumbar Sympathetic Ganglia. A decided increase of temperature, moreover, has been found to take place in the inner fingers, when the vaso-motor fibres contained in the

ulnar nerve were paralyzed by applying a freezing mixture to its trunk at the elbow. — Among the most important influences thus exerted by the Sympathetic system, is doubtless to be ranked the regulation of the amount of secretions furnished by the several *Glands*. There are some Glands whose secretions are specially influenced by states of Mind; such are the Lachrymal, the Salivary, the Gastric, and the Mammary; these are supplied by nerves from the Cerebro-spinal system, as well as by the Sympathetic; and there is experimental evidence that the amount of their secretions is capable of being influenced through those nerves. On the other hand, those portions of the Glandular apparatus the amount of whose secretions is affected only by states of other parts of the Visceral apparatus, are supplied by the Sympathetic exclusively or nearly so. It would even appear that in the former case an active *dilating* influence is exerted through the Cerebro-spinal nerves; so marked is the decrease in the secretion when they are divided.—In none of these instances can any exertion of the *Will* affect the calibre of the blood-vessels; but how strongly *Emotional* states can influence it is seen in the familiar act of blushing.

929. But there is evidence, further, that the Nervous power may be exerted in altering not merely the *quantity* but the *quality* of secretions, and in modifying the Nutritive processes; and that its influence in this direction has its central origin rather in the Sympathetic than in the Cerebro-spinal system, although its transmission may be through the trunks of the latter. Of this we have a remarkable example in the disorganizing inflammation of the Eye, which is a constant sequence of division of the trunk of the Fifth pair on the *distal* side of the Gasserian ganglion, or of its Ophthalmic branch. That this is not due, as has been supposed, to the loss of tactile sensibility in the Conjunctival surface, and the want of the protective secretion called forth by irritation of that surface, appears from the fact that if the division of the trunk be made on the *proximal* side of the ganglion, so that the nerve-fibres proceeding from it and from the Sympathetic filaments which join the trunk in the same part can still proceed to the eye-ball without interruption, the derangement of its nutrition is either wanting altogether, or is greatly diminished in intensity. Similar differences have been observed after section of the ordinary Spinal nerves, according as it is made on the distal or the proximal side of the ganglion; and it may therefore be inferred that the influence exerted through the Cerebro-spinal nerves upon Nutrition, really has its source in the Sympathetic fibres proceeding from the Spinal ganglia contained in their posterior roots, and entering their trunks from the Pre-vertebral ganglia.

930. On the whole it may be stated that the Sympathetic system is the special channel (1) for the transmission of impressions

which produce reflex actions through its own ganglionic centres, between the various organs which it supplies; that (2) by its communications with the Cerebro-spinal system it can transmit impressions of a certain strength to the *centres* of that system, so as to call-forth sensations, whilst it can also transmit from those centres the motor impulses responding to such sensations, or excited by Emotional conditions of the mind; and that (3) it can transmit through the same communicating branches, the influences reflected from *its own* centres to the *peripheral* parts of the Cerebro-spinal system. And thus it is found, especially by Pathological observation, that irritation applied to parts supplied by the Sympathetic system may be propagated to great distances, and may exert an influence either on striated or on non-striated Muscular tissue, producing spasmodic or persistent contraction or atrophy; or upon Nervous tissue, producing paralysis, anæsthesia, or hyperæsthesia; or upon Glandular structures, causing increased, diminished, or altered secretion; or lastly upon the substance of the Tissues themselves, effecting a modification in their nutrition, as indicated by alterations in their structure and by changes in their temperature and vital properties. The effects of irritation of the peripheral branches of the Sympathetic upon the voluntary Muscles are witnessed in the strabismus and epileptiform seizures which are frequently occasioned by the presence of worms in the intestinal canal; whilst the influence exerted upon unstriped muscle is seen in the irregular actions of the walls of the intestines occasioned by the passage of unwholesome substances through the alimentary canal, and in the contractile action which is induced in the uterus by the ingestion of particular substances. The influence of such irritation in producing reflex paralysis, or some other symptom indicative of disorder of the Nervous system, is shown in the induction of paraplegia by disease of the bladder, prostate, and kidney, and in children by irritation of the dental nerves or of the bowels; and there is strong reason to refer to the same agency such symptoms as flying muscular pains, formication, numbness, 'dying-out' of one or more fingers, and local paralyses, occurring in phthisis, scurvy, lead-poisoning, &c. In addition to the examples already given of the influence of nervous impressions transmitted from a distant part upon the operations of Secretion and Nutrition, a case may be mentioned in which after division of the œsophagus (which must have interrupted the transmitting power of the Pneumogastric branches) a quantity of saliva amounting to from four to six ounces was secreted during the injection of a meal of broth into the stomach; whilst in a dog in which a gastric fistula had been established, it was observed that a secretion of gastric juice followed injections of warm water into the rectum. In these cases it seems clear that the agency of the Sympathetic system was alone concerned.—Thus it may be

stated, generally, that the function of the Sympathetic system is (1) to keep the various Organic functions in harmonious relation to each other, and (2) to bring them into relation with the functions of Animal life. But the same agency which maintains this harmony while the entire apparatus is in perfect working order, will produce discord when any portion of it is disturbed; and it cannot be doubted that the 'morbid sympathies' hence arising form a very important part of the phenomena of Disease.

CHAPTER XIV.

OF SENSATION, GENERAL AND SPECIAL.

1. *Of Sensation in general.*

931. ALL save the lowest kinds of Animals possess (there is good reason to believe) a *consciousness* of their own existence, first excited by the corporeal changes taking-place within themselves, and also a greater or less amount of *sensibility* to the condition of external things. This consciousness of what is taking-place within and around the individual, is all derived from *impressions* made upon its afferent nervous fibres; which, being conveyed by them to the central *sensorium*, are there *felt* (§ 389). Of the mode in which the impression, hitherto a change of physical character, is there made to act upon the *mind*, we are absolutely ignorant; we only know the fact. Although we commonly refer our various sensations to the peripheral parts,—as, for instance, when we say that we have a pain in the hand, or an ache in the leg,—we really use incorrect language; for though we instinctively refer our sensations to the parts where the impression is first made on the nerves, they are really *felt* in the brain. This is evident from two facts;—first, that if the nervous communication between the part and the brain be interrupted, no impressions however violent can make themselves felt; and second, that if the *trunk* of the nerve be irritated or pinched anywhere in its course, the pain which is felt is referred, not to the point injured, but to the surface on which these nerves are distributed. Hence the well-known fact, that for some time after the amputation of a limb, the patient feels pains which he refers to the fingers or toes that have been removed; and these continue until the irritation of the cut extremities of the nervous trunks has subsided.

932. It would seem probable that among the lower tribes of

Animals, there exists no other kind of sensibility than that termed *general* or *common*; which pervades, in a greater or less degree, nearly every part of the bodies of the higher. It is by this that we feel those impressions made upon our bodies by the objects around us, which produce the various modifications of *pain*, the sense of contact or resistance, the sense of variations of temperature, and others of a similar character. From what was formerly stated (§ 401) of the dependence of the *impressibility* of the sensory nerves upon the activity of the circulation in the neighbourhood of their extremities, it is obvious that no parts destitute of blood-vessels can receive such impressions, or (in common language) can possess sensibility. Accordingly we find that the hair, nails, teeth, cartilages, and other parts that are altogether extra-vascular, are themselves destitute of sensibility; although certain parts connected with them, such as the bulb of the hair, or the vascular membrane lining the pulp-cavity of the tooth, may be acutely sensitive. Again, in tendons, ligaments, fibro-cartilages, bones, &c., whose substance contains very few vessels, there is but a very low amount of sensibility. On the other hand, the skin and other parts, which are peculiarly adapted to receive such impressions, are extremely vascular; and it is interesting to observe that some of the tissues just mentioned become acutely sensible, when new vessels form in them in consequence of diseased action. It does not necessarily follow, however, that parts should be sensible in a degree proportional to the amount of blood they may contain; for this blood may be sent to them for other purposes, and they may contain but a small number of sensory nerves. Thus, although it is a condition necessary to the action of Muscles, that they should be copiously supplied with blood (§ 335), they are by no means acutely sensible; and in like manner, Glands, which receive a large amount of blood for their peculiar purposes, are far from possessing a high degree of sensibility.

933. But besides the *general* or *common* sensibility, which is diffused over the greater part of the body in most animals, there are certain parts which are endowed with the property of receiving impressions of a peculiar or special kind, such as sounds or odours, that would have no influence on the rest; and the sensations which these excite, being of a kind very different from those already mentioned, arouse ideas in our minds such as we should never have gained without them. Thus, although we can acquire a knowledge of the shape and position of objects by the Touch, we could form no notion of their colour without Sight, of their sounds without Hearing, or of their odours without Smell. The nerves which convey these *special* impressions, as already mentioned, are not able to receive those of a *common* kind; thus the eye, however well fitted for seeing, would not feel the touch

of the finger if it were not supplied by branches from the Fifth pair as well as by the Optic; and when either the Olfactive, Optic, or Auditory nerves are pinched, torn, or cut, no indications of pain are given by the animal. Nor can the different nerves of special sensation be affected by impressions that are adapted to operate on others; thus the Ear cannot distinguish the slightest difference between a luminous and a dark object; nor can the Eye distinguish a sounding body from a silent one unless the vibrations can be *seen*. But pressure on the Eye-ball in the dark excites the sensation of light and colours; strong pressure on the Ear produces *tinnitus aurium;* even sensations of Taste and Smell may be excited by mechanical irritation of their organs. And Electricity possesses the remarkable power, when transmitted along the several nerves of special sense, of exciting sensations peculiar to each; and thus may be made to produce flashes of light, distinct sounds, a phosphoric odour, a peculiar taste, and a pricking feeling, in the same individual, at one time. The feeling of *pain*, however, may be induced by the peculiar impressions made through their appropriate organs upon the nerves of special, as well as upon those of common sensation, if these impressions be too violent or excessive. Thus the dazzling of the eye by a strong light, and still more, the action of a moderate light in an irritable state of the retina,— sudden loud sounds, or even sounds of moderate intensity but of peculiar harshness,— powerful odours, even such as are agreeable in moderation,— produce feelings of uneasiness which may be properly called painful.

934. As a general rule, it may be stated that the *violent* excitement of *any* sensation is disagreeable; even when the same sensation, experienced in a moderate degree, may be a source of extreme pleasure. But the question of degree is *relative* rather than *absolute;* that is, a sensation may be felt as extremely violent by one individual; whilst another, who is more accustomed to sensations of the same kind, is not disagreeably affected by it. So again, our sensations of heat and cold are entirely governed by the previous condition of the parts affected; as is shown by the well-known experiment of putting one hand into hot water, the other into cold, and then transferring them both to tepid water, which will seem cool to the one hand, and warm to the other. The same is the case in regard to light and sound, smell and taste. A person going out of a totally dark room into one moderately bright, is for the time painfully impressed by the light, but soon becomes habituated to it; whilst another who enters it from a room brilliantly illuminated, will consider it dark and gloomy.— The intensity with which sensations are felt, therefore, depends upon the degree of *change* which they produce in the Sensorium. The more frequent the recurrence of any particular sensation, the more does the system become adapted to it, and the less

change does it produce. It is, therefore, perceived in a less and less degree, and at last it ceases to excite attention. The *stoppage* of a constantly-recurring sensation, however, will produce a change which makes as strong an impression on the system as its first commencement: thus there are persons who have become so habituated to the sound of a waterfall or even of a forge-hammer, that they cannot sleep anywhere but in its vicinity; and it is well-known that when a person has gone to sleep under the influence of some continuous or frequently-recurring sound (such as the voice of a reader, the dropping of water, the tread of a sentinel, &c.), the cessation of the sound will cause his awaking.

935. The acuteness of particular sensations is influenced in a remarkable degree by the *attention* they receive from the mind. If the mind be entirely inactive, as in profound sleep, no sensation whatever is produced by very feeble impressions; on the other hand, when the mind is from any cause strongly directed upon them, impressions very feeble in themselves produce sensations of even painful acuteness. It is in this manner that the habit of attending to sensations of any particular class increases their vividness; so that they are at once perceived by an individual on the watch for them, when they do not excite the observation of others. We may even by a strong effort so limit the attention to one special subject, as to receive only those sensations which have reference to it, and to be unconscious *quoad* all others. Thus the application of the mind to some particular train of thought may prevent our being conscious of anything that is going-on around or within us,—the conversation of friends,—the striking of the clock,—the calls of hunger, &c. This *abstraction* may be altogether voluntary; and the possession of the power of thus withdrawing the mind at will from the influence of external disturbing causes, and of fixing it upon any particular train of ideas, is an extremely valuable one. But it may also be involuntary, and may be a source of inconvenience from its tendency to recur at improper times,—producing the habitual state which is known as *absence of mind* or *reverie.*

936. It is desirable that we should make a distinction between the *sensations* themselves, and the *ideas* which are the immediate results of those sensations when they are perceived by the mind. These ideas relate to the *cause* of the sensations, or the object by which the impression is made. Thus the formation of the picture of an object upon the retina produces a certain impression upon the optic nerve which, being conveyed to the sensorium, excites a corresponding sensation; and with this, in all ordinary cases, we immediately connect an idea of the nature of the object. So closely, indeed, is this idea usually related to the sensation, that we are not in the habit of making a distinction between them. Thus I may say at this moment, "I see a book on the

table before me;" the fact being, that I am conscious of a certain picture, which conveys to my mind the ideas of a book and of a table, and of their relative positions; these ideas being (in Man) the result of experience and association,— in fact, originating in the immediate application of the knowledge we have previously acquired, that a certain object whose picture we see is a book, another object a table, and so on. We are liable to be deceived in this assumption; as when, by a clever imitation, a picture on a plane surface is made to represent an object in relief, so perfectly as at once to excite the idea of the latter,— which may not be corrected until we have ascertained by the touch the flatness of the real object.

937. This production of ideas by the agency of sensations is a process essentially mental, and dependent upon the laws of Mind. We find that some of these *perceptions* or elementary notions are *intuitive:* that is, they are prior to all experience, and are as *necessarily* connected with the sensations which produce them as reflex movements are with the impressions that excite them. This seems to be the case, for, example, with regard to *erect vision.* There is no reason whatever to think, that either infants or any of the lower animals see objects in an inverted position until they have corrected their notion by the touch; for there is no reason why the inverted picture on the retina should give rise to the idea of the inversion of the object. The picture is so received by the mind, as to convey to us an idea of the position of external objects which harmonizes with the ideas we derive through the touch; and whilst we are in such complete ignorance of the manner iu which the mind becomes conscious of the sensation at all, we need not feel any difficulty about the mode in which this conformity is effected. But in Man, as already stated, the attaching definite ideas to certain groups of lines, colours, &c., with respect to the objects they represent, is a subsequent process, in which experience and memory are essentially concerned; as we see particularly well in cases presently to be referred-to, in which the sense of sight has been acquired comparatively late in life, and in which the mode of using it, and of connecting the sensations received through it with those received through the touch, has had to be learned by a long-continued training. The elementary notions thus formed,—which may, by long habit, present themselves as immediately and unquestionably as if they were intuitive,—are termed *acquired* perceptions (§§ 961—967).

938. It is probable that among the lower animals the proportion of intuitive perceptions is much greater than in Man; whilst, on the other hand, their power of acquiring perceptions is much less than his. Hence, whilst the young of any of the lower animals very soon becomes possessed of all the knowledge which is

necessary for the acquisition of its food, the construction of its habitation, &c., its range is very limited, and it is incapable of attaching any ideas to a great variety of objects of which the Human mind takes cognizance. This correspondence between the acquired perceptions of Man, and the intuitive perceptions of many of the lower animals, is strikingly evident in regard to the power of measuring distance. This is acquired very gradually in the Human infant, or by a person who has first obtained the faculty of sight later in life; but it is obviously possessed by many of the lower animals to whose maintenance it is essential, immediately upon their entrance into the world. Thus a Fly-catcher, immediately after its exit from the egg, has been known to peck-at and capture an insect,—an action which requires a very exact appreciation of distance, as well as a power of precisely regulating the muscular movements in accordance with it.

2. *Of the Sense of Touch.*

939. By the sense of Touch is usually understood that modification of the common sensibility of the body, of which the surface of the Skin is the especial seat, but which exists also in some of its internal reflexions. In some animals, as in Man, nearly the whole exterior of the body is endowed with it in no inconsiderable degree; whilst in others, as the greater number of Mammalia, most Birds, Reptiles, and Fishes, and a large proportion of the Invertebrata, the greater part of the body is so covered with hairs, scales, bony or horny plates, shells of various kinds, complete horny envelopes, &c., as to be nearly insensible; and the faculty is restricted to particular portions of the surface, or to organs projecting from it, which often possess a peculiarly high degree of this endowment. Even in Man, the acuteness of the sensibility of the cutaneous surface varies greatly in different parts; being greatest at the extremities of the fingers and in the lips, and least in the skin of the trunk, arm, and thigh. Thus the two points of a pair of compasses (rendered blunt by bits of cork) can be separately distinguished by the point of the middle finger, when approximated so closely as 1-3rd of a line; whilst they require to be opened so widely as 30 lines from each other to be separately distinguished, when pressed upon the skin over the spine, or upon that of the middle of the arm or thigh.—The impressions that produce the sense of Touch are most distinct when received through the sensory *papillæ*, with which the surface of the true Skin is found beset more or less closely, according to the part of it that is examined. These papillæ are minute elevations, which have been commonly stated to enclose loops of capillary vessels (Fig. 238) and branches of the sensory nerves. The recent observations of Wagner, Kölliker, and others, how-

ever, render it probable that the papillæ are essentially of two kinds; namely, the *vascular* (Fig. 184, *p*), which are especially destined to afford nutrition to the epidermis, and which are extraordinarily developed in the matrices of nails, hoofs, &c.; and the *nervous* papillæ (*t*), which are purely sensory. Whether the latter uniformly contain blood-vessels, or as a rule, are destitute of them, must be considered as still doubtful; it is certain, however, that their supply of blood is much inferior to that of the vascular papillæ. The cutaneous nerves form a plexus (§ 381), from which fibres proceed to the sensory papillæ (Fig. 239, *c, c, c*); and these fibres seem to be distributed (in those parts, at least, which are distinguished by acuteness of

Fig. 238*.

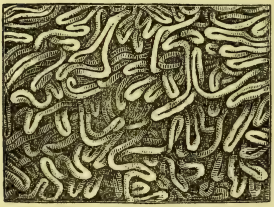
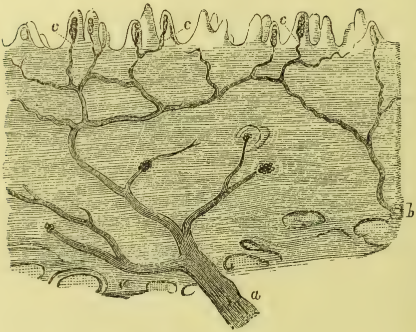


Fig. 239.†



tactile sensibility) on a peculiar 'axile' body, which occupies the principal part of the interior of the papilla, and which may be

* Capillary network at margin of Lips.

† Vertical Section of the Skin of the palmar surface of the fore-finger (treated with a solution of caustic soda), showing the branches of cutaneous nerves, *a. b*, inosculating to form a terminal plexus, of which the ultimate ramifications pass into the cutaneous papillæ, *c, c, c*.

considered as formed by an increased development of the fibrous tissue that forms the neurilemma of the nerve-tubes. These 'axile' bodies, not being constantly present in the sensory papillæ, cannot be considered as essential to the exercise of the sense of Touch; and it rather seems to be their function to intensify tactile impressions, where delicacy of touch may be specially required.

940. It is peculiar to the sense of Touch and of Taste (the latter being in this respect closely allied to the former), that the impression must be made by the *contact* of the object itself with the sensory surface, and not through any intermediate agency. The only exception to this is in regard to the sense of *Temperature*, which seems to be in many respects different from ordinary touch: here the *proximity* of the warm or cold body is sufficient, the impressions being made after the manner of those of odours, sounds, &c.; and no mechanical irritation of the nerves of common sensation ever seems to excite sensations of heat or cold.

941. For the exercise of the sense of Temperature, the integrity of the sensory apparatus contained in the Skin appears to be requisite; for it has been ascertained by the experiments of Prof. Weber, that if the integuments be removed, the application of hot or cold bodies only causes *pain*, their elevation or depression of temperature not being perceived; and the same is the case when hot or cold bodies are applied to the nerve-trunks. It is worthy of note that there are many cases on record in which the sense of Temperature has been lost, while the ordinary Tactile sense remained; and the former is sometimes preserved when there is a complete loss of every other kind of sensibility. It is even maintained by Dr. Brown-Séquard that there are different conductors in the Spinal cord for the sensations of touch, pain, temperature, and muscular contraction, none of which can convey other impressions than their own; and if this be the case, it would seem probable that there are different nerve-fibres ministering to these several kinds of impressions. That the ordinary tactile nerves are different from those which convey the sense of pain, would also appear from the well-known fact that the sense of pain is often extinguished by anæsthetic agents, whilst that of touch remains. So again we find that the *subjective* sensations of temperature (that is, sensations which originate from changes in the body itself, not from external impressions) are frequently excited quite independently of the tactile sensations; a person being sensible of heat or of chilliness in some part of his body, without any real alteration of its temperature, and without any corresponding affection of the tactile sensations.—It is curious that the intensity of the sensation of temperature should depend, not merely upon the relative degree of heat to which the part is exposed (§ 934), but also upon the extent of the surface over which it is applied; a weaker impression made on a larger surface,

seeming more powerful than a stronger impression made on a small surface. Thus, if the forefinger of one hand be immersed in water at 104°, and the whole of the other hand be plunged in water at 102°, the cooler water will be thought the warmer; whence the well-known fact, that water in which a finger can be held without discomfort, will produce a scalding sensation when the entire hand is immersed in it.

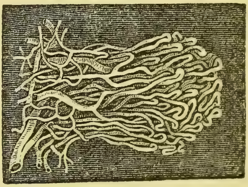
942. The only idea communicated to our minds when the sense of Touch is exercised in its simplest form, is that of *resistance;* and we cannot acquire a notion of the size or shape of an object, or the nature of its surface, through this sense alone, unless we *move* the object over our own sensory organ, or pass the latter over the former. By the various degrees of resistance which we then encounter, we form our estimate of the hardness or softness of the body. By the impressions made upon our sensory papillæ, when they are moving over its surface, we form our idea of its smoothness or roughness. But it is through the *muscular* sense, which renders us cognizant of the relative position of the fingers, the amount of movement the hand has performed in passing over the object, and other impressions of like nature, that we acquire our notions of its size and figure; and hence we perceive that the sense of touch, without the power of giving motion to the tactile organ, would have been of comparatively little use. It is chiefly in the *variety* of movements of which the hand of Man is capable,—thus conducive as they are, not merely to his prehensile powers, but to the exercise of his sensory endowments,—that it is superior to that of any other animal; and it cannot be doubted that this affords us a very important means of acquiring information in regard to the external world, and especially of correcting many vague and fallacious notions which we should derive from the sense of Sight if used alone. On the other hand, it must be evident that our knowledge would have but a very limited range, if this sense were the only medium through which we could acquire ideas. Of this we have the clearest evidence in the very imperfect development of the mental powers in those unfortunate persons, who have suffered under the deprivation of sight and hearing from their birth, and who have been consequently cut-off from the most direct means of profiting by the knowledge possessed by their fellow-beings, through want of power to use the organs of speech. It is only where such individuals have fallen under the care of judicious and persevering instructors, that their mental powers have been called into their due activity, or that any ideas have been awakened beyond those immediately connected with the gratification of the animal wants, or with painful or pleasurable sensations. Thus a mind quite capable of being aroused to activity and enjoyment, may remain in a condition nearly allied to that of idiocy, simply for want of the sensations requisite to

produce ideas of a higher or more abstract character, than those derived through the senses of Touch, Taste, and Smell.

3. *Of the Sense of Taste.*

943. The sense of Taste, like that of Touch, is excited by the direct contact of particular substances with certain parts of the body: but it is of a nature different from that of touch, inasmuch as it communicates to us a knowledge of properties which that sense would not reveal to us (§ 945). All substances, however, do not make an impression on the organ of Taste. Some have a strong savour, others a slight one, and others are altogether insipid. The cause of these differences is not altogether understood; but it may be remarked that, in general, bodies which cannot be dissolved in water, alcohol, &c., and which thus cannot be presented to the gustative papillæ in a state of solution, have no taste; and further, that the taste of *colloid* bodies, whose osmotic power is very feeble, is much less strong than that of *crystalloid* bodies, whose diffusive power will more rapidly bring them to act on the extremities of the nerves (§ 491). This sense has for its chief purpose to direct animals in their choice of food; hence its organ is always placed at the entrance to the digestive canal. In higher animals the Tongue is the principal seat of it; but other parts of the mouth are also capable of receiving the impression of certain savours. The mucous membrane which covers the tongue is copiously supplied with papillæ of various forms and sizes. Those of simple structure closely resemble the cutaneous papillæ; but there are others which resemble clusters of such papillæ, each being composed of a fasiculus of looped capillaries (Fig. 240), with a bundle of nerve-fibres, whose precise mode of termination it has not yet been found possible certainly to ascertain. These *fungiform* papillæ, which are covered with a very thin epithelium, are probably the special instruments of the sense of taste; for the exercise of which it seems probable that the sapid substances must penetrate (in solution) to the interior of the papilla. When these papillæ are called into action by the contact of substances having a strong savour, they not unfrequently become very turgid, by a distension of their vessels analogous to that which occurs in 'erection;' and they rise-up above the level of the mucous membrane, so as to produce a

*Fig. 240.**



* Capillary network of Fungiform papilla of the Tongue.

decided roughness of its surface.—The *conical* papillæ, on the other hand, are furnished with thick epithelial investments, which are sometimes prolonged into filamentous appendages; and looking to their higher development among other animals, and the offices to which they are there subservient, it seems probable that *their* functions are purely mechanical, and that they serve especially to cleanse the teeth from adhering particles. The nerve-fibres can be seen to form distinct loops in their interior, at some distance from their apex.

944. There has been much discrepancy of opinion as to the nerve which is especially concerned in the sense of Taste. The tongue of Man is supplied by two sensory nerves; the Lingual branch of the Fifth pair and the Glosso-pharyngeal. The former chiefly supplies the upper surface of the front of the tongue, and is copiously distributed to the papillæ near the tip. The latter is mostly distributed upon the mucous surface of the fauces, and upon the back of the tongue; but it sends a branch forwards, beneath the lateral margin on each side, which supplies the edges and inferior surface of the tip of the tongue, and inosculates with the preceding. There is reason to believe from experiments that the gustative sensibility of the tongue is not destroyed by section of either of these nerves, though the operation produces a total or partial loss of sensibility over certain parts of the surface; and a like inference may be drawn from observation of cases of paralysis. From these and other considerations there seems good reason to conclude, that the Lingual branch of the Fifth pair is the nerve through which the sense of Taste, as well as that of Touch, is exercised, in the parts of the tongue to which it is specially distributed, which are those that possess both senses in the most acute degree; and that the Glosso-pharyngeal is subservient to the same functions in the parts supplied by *it*,—being probably the exclusive channel, also, through which the impressions made by disagreeable substances taken into the mouth are propagated to the Medulla Oblongata, so as to produce nausea and excite efforts to vomit. The latter nerve is also, as we have seen, the principal channel of the impressions that give rise to the reflex act of swallowing; with which the fifth pair is concerned in a much inferior degree (§ 897).

945. A considerable part of the impression produced by many substances taken into the mouth, is received through the sense of Smell, rather than through that of Taste. Of this any one may easily satisfy himself by closing the nostrils and breathing through the mouth only, whilst holding in his mouth, or even rubbing between his tongue and his palate, some aromatic substance; its taste is then scarcely recognized, although it is immediately perceived when the nasal passages are re-opened, and its effluvia are drawn into them. There are many substances, however, which

have no aromatic or volatile character; and whose taste, though not in the least dependent upon the action of the nose, is nevertheless of a powerful character. Some of these produce, by irritating the mucous membrane, a sense of *pungency*, allied to that which the same substances (mustard, for instance) will produce, when applied to the skin for a sufficient length of time, especially if the Epidermis have been removed. Such sensations, therefore, are evidently of the same *kind* with those of Touch, differing from them only in the *degree* of sensibility of the organ through which they are received. But there are others which produce sensations entirely different from any that can be received through the skin, and which are properly distinguished, therefore, as *gustative;* such are common Salt, which may be considered as a type of the saline taste, Sugar the type of the saccharine, Quinine of the bitter, Tannin of the astringent, and Citric acid of the sour. All such substances, therefore, are said to possess *sapid* properties, exciting distinctive tastes, quite irrespectively of any aromatic or odorous properties which they may also possess, as well as of their stimulating action on the skin. It has been ascertained by the experiments of Prof. Valentin that a solution of *one* part of Quinine in *a million* parts of water may be distinguished by careful comparison from perfectly pure water.

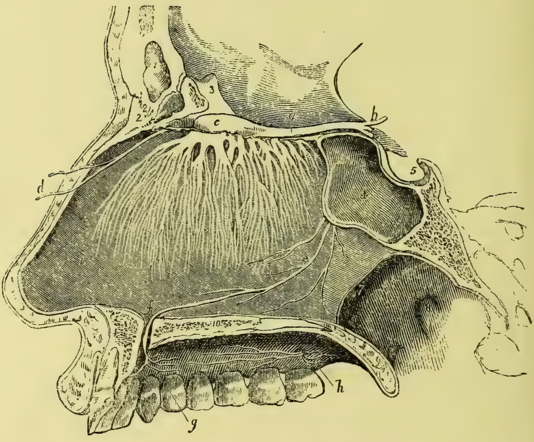
4. *Of the Sense of Smell.*

946. Certain bodies possess the property of exciting sensations of a peculiar nature, which cannot be perceived by the organs of taste or touch, but which seem to depend upon the diffusion of the particles of the substance through the surrounding air, in a state of extreme minuteness. As the solubility of a substance in liquid seems a necessary condition of its exciting the sense of taste, so does its volatility, or tendency to a vaporous state, appear requisite for its having Odorous properties. Most volatile substances are more or less odorous; whilst those which do not readily transform themselves into vapour usually possess little or no fragrance in the liquid or solid state, but may acquire strong odorous properties as soon as they are converted into vapour,—by the aid of heat, for example. There are some solid substances, however, which possess very strong odorous properties, without losing weight in any appreciable degree by the diffusion of their particles through the atmosphere. This is the case, for example, with Musk; a grain of which has been kept freely exposed to the air of a room whose door and windows were constantly open, for a period of ten years; during which time the air, thus continually changed, was completely impregnated with the odour of musk; and yet, at the end of that time, the particle was not found to have perceptibly diminished in weight. We can only attribute

this result to the extreme minuteness of the division of the odorous particles of this substance. There are other odorous solids, such as Camphor, which rapidly lose weight by the loss of particles from their surface, when freely exposed to the air.

947. The Olfactory nerves pass down from the Olfactory ganglia in numerous very minute threads, which form a plexus upon the surface of the Schneiderian or pituitary membrane. The ultimate fibres of this plexus are of the 'gelatinous' kind (Fig. 107),

Fig. 241.*



* The Olfactory nerve, with its distribution on the Septum Nasi: the nares have been divided by a longitudinal section made immediately to the left of the septum, the right nares being preserved entire:—1, The frontal sinus; 2, the nasal bone; 3, the crista galli process of the ethmoid bone; 4, the sphenoidal sinus of the left side; 5, the sella turcica; 6, the basilar process of the sphenoid and occipital bones; 7, the posterior opening of the right nares; 8, the opening of the Eustachian tube in the upper part of the pharynx; 9, the soft palate, divided through its middle; 10, cut surface of the hard palate: -*a*, the olfactory peduncle; *b*, its three roots of origin; *c*, olfactory ganglion, from which the filaments proceed that spread-out in the substance of the pituitary membrane; *d*, the nasal nerve, a branch of the ophthalmic nerve descending into the left nares from the anterior foramen of the cribriform plate, and dividing into its external and internal branch; *e*, the naso-palatine nerve, a branch of the spheno-palatine ganglion distributing twigs to the mucous membrane of the septum nasi in its course to (*f*) the anterior palatine foramen, where it forms a small gangliform swelling (Cloquet's ganglion) by its union with its fellow of the opposite side; *g*, branches of the naso-palatine nerve to the palate; *h*, posterior palatine nerves; *i*, *i*, the septum nasi.

being nucleated and finely granular in texture, and destitute of medullary sheath. Their distribution is limited to the membrane covering the upper part of the nasal fossæ; the surface to which they are restricted being distinguished by the rich sepia-brown hue of its epithelium. The cells of this epithelium are greatly elongated or rod-like; they are composed of protoplasmic segments not enclosed by any distinct membrane at their free extremities; and whilst some of them appear to become continuous at their attached extremities with the subjacent connective-tissue-corpuscles (like the epithelial cells of the intestinal villi, § 494), others seem to come into similar relation with the ultimate fibrils which are formed by the subdivision of the nerve-fibres.—The Schneiderian membrane is kept constantly but moderately moist by a mucous secretion from its surface; and this condition is essential to the acute perception of odours. If the mucous surface be too dry, as happens when the Fifth pair is paralysed, the sensation is blunted or even destroyed; and the same effect is produced by the presence of too copious a secretion, as when we are suffering under an ordinary 'cold.'—It is evidently from the limitation of Olfactive sensibility to the highest part of the nasal fossæ, that when we *snuff* the air, so as to direct it into this portion of the cavity, we perceive delicate odours which would otherwise have escaped us. The acuteness of the sense of Smell depends, in no small degree, upon the extent of surface exposed by the membrane lining the nasal cavity; and in this respect Man is far surpassed by many of the lower Mammalia, especially the Ruminants, which are warned by its means of the proximity of their enemies. The habit of *attention* to sensory impressions of this class, however, very much heightens their acuteness; hence in those who suffer under blindness and deafness conjointly, it is usually the principal means by which individuals are distinguished and the presence of strangers recognised; and there are cases in which individuals in a state of Somnambulism (in which there is often an extraordinary concentration of the mind upon some one particular kind of sensory impressions) have exhibited a degree of acuteness of smell quite comparable to that which is characteristic of Deer, Antelopes, &c.

948. Besides ministering to the sense of Smell by stimulating the secreting powers of its surface, the Fifth pair has another very important function,—that of endowing the interior of the nasal cavity with *common* sensibility, and thus receiving the impressions produced by acrid or pungent substances, which act upon it in the same way as they do upon the tongue. Such substances are *felt*, by the irritation they produce, rather than *smelt*; and the sensation they occasion gives-rise to the consensual act of *sneezing*, by which a violent blast of air is directed through the nasal passages, in such a manner as to clear them of the irritating

matter, whether solid (as snuff), liquid, or gaseous. Hence this action may be excited by the contact of an irritant with the Schneiderian membrane, after the Olfactory nerve has been divided, if the branches of the Fifth pair be entire: whilst it does not take-place when the fifth pair is paralysed, even though the sense of smell is retained.

5. *Of the Sense of Hearing.*

949. Through this sense we become acquainted with the Sounds produced by bodies in a certain state of vibration; the vibrations being propagated through the surrounding medium by the corresponding waves or undulations which they produce in it. Although air is the usual medium through which sound is propagated, yet liquids or solids may answer the same purpose. On the other hand, no sound can be propagated through a perfect vacuum.—It is a fact of much importance, in regard to the action of the Organ of Hearing, that sonorous vibrations which have been excited, and are being transmitted, in a medium of one kind, are not imparted with the same readiness to others. The following conclusions have been drawn from experimental inquiries on this subject:—

I. Vibrations excited in solid bodies may be transmitted to water without much loss of their intensity; although not with the same readiness that they would be communicated to another solid.

II. On the other hand, vibrations excited in water lose something of their intensity in being propagated to solids; but they are returned, as it were, by these solids to the liquid, so that the sound is more loudly heard in the neighbourhood of these bodies than it would otherwise have been.

III. The sonorous vibrations are much more weakened in the transmission of solids to air; and those of air make but little impression on solids.

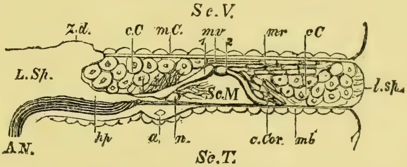
IV. Sonorous vibrations in water are transmitted but feebly to air; and those which are taking-place in air are with difficulty communicated to water; but the communication is rendered more easy by the intervention of a membrane extended between them.

The application of these conclusions, in the Physiology of Hearing, will be immediately apparent.

950. It is on the *Auditory* nerve (commonly termed the Portio Mollis of the 7th pair), that the sonorous undulations make their impression; but we invariably find that this impression is made through the medium of a liquid contained in a cavity, on the walls of which the ultimate branches of this nerve are distributed. Of the distribution of the ultimate fibrils of the Auditory nerve, little

is certainly known, although it has been most carefully studied, especially in the *lamina spiralis* of the Cochlea. The results of that study, however, seem to show a close analogy between the mode of termination of those fibrils, and that in which the fibrils of the Optic nerve terminate in the Retina (§ 960); for the branches of the Auditory nerve (Fig. 242, A N), which are distributed on the under side of the osseous portion of the *lamina spiralis* (*L. Sp.*) penetrate its projecting margin or *habenula perforata* (*h. p.*) by many small openings, and thus find their way to the space between

Fig. 242.*



the two layers of periosteal membrane which continue the lamina spiralis to the opposite wall; the upper of these layers (*m. C.*) being known as the *membrane of Corti*, and the lower (*m. b.*) as the membrana basilaris. The space between these membranes is occupied by the *rods of Corti* (1, 2) which form an angle with one another like the gable of a house, the large *cells of Claudius* (*c. C.*), the *cells of Corti* (*c. Cor.*), and the cavity termed *Scala Media* (*Sc. M.*) which is filled with liquid; and among these structures the ultimate fibrils of the Auditory nerve appear to terminate by free and extremely delicate extremities.—The simplest form of the organ of Hearing, such as we find in Cephalopods and in certain Fishes, consists merely of a cavity excavated in the solid framework of the head; which cavity is filled with liquid, and is

* Vertical Section of the Lamina Spiralis of the Cochlea, dividing the Scala Vestibuli (*Sc. V.*) from the Scala tympani (*Sc. T.*):—*L. Sp.*, osseous portion of the lamina spiralis; from the upper margin of which, the zona denticulata (*z. d.*), is prolonged the Membrane of Corti (*m. C.*), which is covered with an epithelial layer; whilst from its lower margin, the habenula perforata (*h.p.*), is prolonged the membrana basilaris (*m. b.*) also covered with epithelium. Between the two is the scala media (*Sc. M.*), which is roofed over by the two sets of rods of Corti (1, 2), which are connected above by a delicate membrane, the membrana velamentosa (*m. v.*). The space between the first set of rods of Corti and the osseous lamina spiralis on the inner side, and that between the second set of rods of Corti and the outer margin of the spiral ligament (*l. sp.*), are occupied by the large nucleated cells of Claudius (*c. C.*); whilst beneath the second set of rods are the cells of Corti (*c. Cor.*). At *A N* is seen one of the terminal twigs of the Auditory nerve, passing towards the scala media; at *n* is seen a well-defined nucleus; *a*, spiral vessel; *m. r.*, membrana reticularis.

lined by a membrane on which the Auditory nerve is distributed. These animals are inhabitants of the water; and the sonorous vibrations excited in this medium, being communicated to the solid parts of the head, will be by them again transmitted to the contained fluid without much diminution of their intensity, according to principles I. and II.—In certain Crustacea, however, whose organ of hearing is contained in the base of the antennæ, as well as in most Fishes, we find the auditory cavity or vestibule no longer entirely closed; but having an aperture on its external side, which is covered-in by a membrane. Here the vibrations of the liquid within the cavity will be more directly excited by those of the surrounding medium; for if this be water, it will propagate its undulations to the liquid within the cavity, with little interruption from the membrane stretched across its mouth; whilst, if it be air, the interposition of this very membrane will greatly assist in the transmission of the vibrations to the liquid of the auditory cavity, according to principle IV. In most of the animals which have the organ of hearing constructed on this simple plan, the force of the vibrations of the liquid within the cavity is increased by several minute stony concretions (termed *otoliths*), which are suspended in it. These act according to principle II. Some traces of them are found in the higher animals; in which, however, they are for the most part superseded by an apparatus better adapted to augment the intensity of the sonorous vibrations.

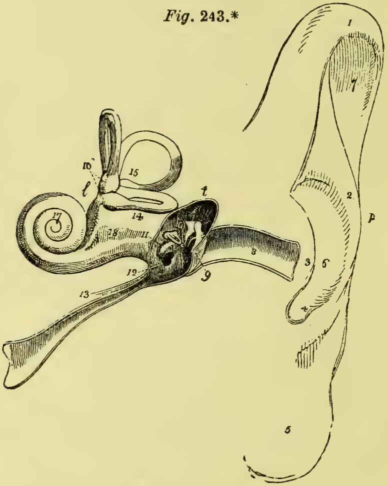
951. This apparatus consists, in all Vertebrate animals above the inferior Reptiles, of the *tympanum* or drum, with its membrane and chain of bones; together with, in the Mammalia, an *external ear*, which is adapted to direct itself, more or less completely, towards the point from which the sonorous vibrations proceed, and seems to give them a degree of preliminary concentration. This power of direction, which is exercised through the muscles attached to the organ, is much greater among the lower Mammalia than it is in Man, in whom these muscles are but very slightly developed.—The Tympanic apparatus is interposed between the external ear and the membrane covering the *foramen ovale*, which is the entrance to the real auditory cavity; and its purpose is evidently to receive the sonorous vibrations from the air, and to transmit them to that membrane, in such a manner that the vibrations thus excited in the latter may be much more powerful than they would be if the air acted immediately upon it, as it does in the lower Vertebrata.—The usual condition of the Membrana Tympani appears to be rather lax; and, when in this condition, it vibrates in accordance with grave or deep tones. By the action of the *tensor tympani* it may be tightened, so as to vibrate in accordance with sharper or higher tones; but it will then be less able to receive the impressions of deeper sounds.

This muscle appears to be antagonized by the *stapedius*, the contraction of which seems to diminish the tension of the membrana tympani, and to take-off pressure from the fluid of the labyrinth. These two muscles conjointly may be considered to *regulate* the transmission of sonorous vibrations to the liquid of the internal sac, preventing it from being too violently affected by loud sounds, in the same manner that the iris regulates the admission of light to the eye; and they are probably put into conjoint action when we are *listening* for faint sounds, so as to bring the Tympanum into the state of tension best adapted to reciprocate them. There are different limits in different persons to the acuteness of the sounds of which the ear can naturally take cognizance. If the sound be so high in pitch that the membrana tympani cannot vibrate in unison with it, the individual will not hear it, even though it be loud; and it has been noticed that certain individuals cannot hear the very shrill tones produced by particular Insects or even Birds, which are distinctly audible to others. Some persons, again, are deaf to grave sounds, whilst they readily hear the more acute.—The chief function of the *Eustachian tube* (which is always found where there is a tympanic cavity) appears to be the maintenance of equilibrium between the air within the cavity and the external air, so as to prevent inordinate tension of the membrane by excess or diminution of pressure on either side. Its guttural orifice is ordinarily closed, and only opens in the act of swallowing; and hence persons who are descending in a diving-bell, and feel pain in the ears from the increase of atmospheric pressure on the exterior of the tympanum, find themselves relieved by swallowing, which, by opening the outlet of the Eustachian tube, restores the equilibrium of pressure. This canal also serves to convey away mucus secreted in the tympanic cavity, by means of the cilia which clothe its lining membrane; and an accumulation of this mucus is one source of the deafness consequent on obstruction of the tube.

952. Not only do we find the tympanic apparatus superadded, in the higher forms of the organ of Hearing, but also the Semicircular Canals (Fig. 243, 15), and the Cochlea (17).—The former exist in all Vertebrata, save the lowest Fishes; and in nearly every case they are *three* in number, and lie in three different planes. Hence it has been supposed, with some probability, that they assist in producing the idea of the *direction* of sounds. The *Cochlea* does not exist at all in Fishes; and in Reptiles its condition is quite rudimentary. This cavity is more completely formed in Birds, though the passage is nearly straight instead of spiral; of its real character, however, there can be no doubt, from its being divided, like the cochlea of Man, by a membranous partition, on which the ramifications of the auditory nerve are spread out. This appendage has been supposed to be the organ that

enables us to judge of the *pitch* of sounds; an idea which derives some confirmation from the correspondence between the development of the cochlea in different animals, and the variety in the

Fig. 243.*



pitch (or length of the scale) of the sounds which it is important that they should hear distinctly, especially the voices of their own kind. And if this be the case, it is not improbable that (as suggested by Prof. Helmholtz) it is the organ by which we are especially enabled to distinguish the *timbre* or peculiar quality of

* A diagram of the Ear:—*p*, The pinna; *t*, the tympanum; *l*, the labyrinth; 1, the upper part of the helix; 2, the antihelix; 3, the tragus; 4, the antitragus; 5, the lobulus; 6, the concha; 7, the upper part of the fossa scaphoidea; 8, the meatus; 9, the membrana tympani, divided by the section; 10, the three little bones, malleus, incus, and stapes, crossing the area of the tympanum, the foot of the stapes blocking up the fenestra ovalis upon the inner wall of the tympanum; 11, the promontory; 12, the fenestra rotunda; the dark opening above the ossicula leads into the mastoid cells; 13, the Eustachian tube; the little canal upon this tube contains the tensor tympani muscle in its passage to the tympanum; 14, the vestibule; 15, the three semicircular canals, horizontal, perpendicular, and oblique; 16, the ampullæ upon the perpendicular and horizontal canals; 17, the cochlea; 18, depression between the convexities of the two tubuli which communicate with the tympanum and vestibule; the one is the scala tympani, terminating at 12; the other is the scala vestibuli.

sounds (§ 954).—That the Vestibule, with the passages proceeding from it, constitutes the true organ of hearing, even in Man, is evident from the fact, that when (as not unfrequently happens) the tympanic apparatus has been entirely destroyed by disease, so as to reduce the organ to the condition of that in which no such apparatus exists, the faculty of Hearing is by no means abolished, although it is deadened.

953. The faculty of Hearing, like other senses, may be very much increased in acuteness by cultivation; but this improvement depends rather upon the habit of *attention* to the faintest impressions made upon the organ, than upon any change in the organ itself. This habit may be cultivated in regard to sounds of some particular class; all others being heard as by an ordinary person. Thus, the watchful North American Indian recognises footsteps, and can even distinguish between the tread of friends and foes; whilst his white companion, who has lived among the busy hum of cities, is unconscious of the slightest sound. Yet the latter may be a musician, capable of distinguishing the tones of all the different instruments in a large orchestra, of following any one of them through the part which it performs, and of detecting the least discord in the blended effects of the whole,—effects which would be to the unsophisticated Indian but an indistinct mass of sound. In the same manner, a person who has lived much in the country is able to distinguish the note of every species of bird that lends its voice to the general chorus of of nature; whilst the inhabitant of a town hears only a confused assemblage of shrill sounds, which may impart to him a disagreeable rather than a pleasurable sensation.

954. In all continued sounds or *tones*, there are several points to be attended-to. In the first place, we take cognizance of their *pitch;* which depends upon the *number* of vibrations in a given time,— the high notes being produced by the most rapid vibrations, and the low notes by the slowest. Some persons can appreciate tones produced by 73,000 impulses per second; the lowest limit being usually 16 vibrations per second. No sequence of vibrations fewer than 7 or 8 in a second can produce a continuous tone, because the impression left by each impulse has passed-away before the next succeeds, so that nothing more is heard than a succession of distinct pulses.— The *strength* or *loudness* of musical tones depends (other things being equal) on the force and extent of the vibrations communicated by the sounding body to the medium which propagates them. This will diminish, however, with distance; which softens loud tones by lowering the intensity of the undulations, as a consequence of their more extensive diffusion. The cause of the differences in the *timbre*, or quality of musical tones,—such, for instance, as those which exist between the tones of a flute, a violin, a trumpet and

a human voice, all sounding a note of the same pitch,—have been shown by the admirable researches of Prof. Helmholtz to consist in differences in the *harmonics* which are combined, in each case respectively, with the fundamental note.— Our ideas of the *direction* and distance of sounds, are for the most part formed by habit. Of the former we probably judge in great degree by the relative intensity of the impressions received by the two ears; though we may form some notion of it by a single ear, if the idea just stated as to the use of the semicircular canals (§ 952), be correct.— Those animals, however, which have the power of freely moving the external ear, will doubtless derive their best indication of the direction of sounds from the muscular movements employed in putting the organ into the best position for their reception.—Of the *distance* of the sounding body, we judge by the intensity of the sound, comparing it with that which we know the same body to produce when nearer to us. The Ear may be deceived in this respect as well as the eye; thus the effect of a full band at a distance may be given by the subdued tones of a concealed orchestra close to us; and the Ventriloquist produces his deceptions by imitating as closely as possible, not the sounds as they would be given-forth, but the sounds as they would strike our ears.

6. *Of the Sense of Sight.*

955. By the faculty of Sight we are made acquainted, in the first place, with the existence of *Light;* and by the medium of that agent we take cognizance of the form, size, colour, position, &c., of bodies that transmit or reflect it. As to the mode in which luminous impressions are propagated through space, philosophers are not yet fully agreed; and the question is of no physiological importance, since all are agreed as to the *laws* which regulate their transmission. These laws, which will be found at large in any Treatise on Natural Philosophy,* may be briefly stated as follows:—

I. Light travels in straight lines, so long as the medium through which it passes is of a uniform density.

II. When the rays of light pass from a rarer medium into a denser one, they are refracted *towards* a line drawn perpendicularly to the surface they are entering.

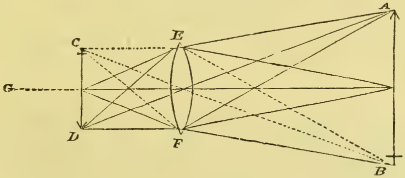
III. When the rays of light pass from a denser medium into a rarer one, they are refracted *from* the perpendicular.

IV. When rays proceeding from the several points of a luminous object at a distance fall upon a double convex lens, they are brought to a focus upon the other side of it; in such a manner that

* See Dr. Golding Bird's Manual, Chap. XIX.

an inverted picture of the object is formed upon a screen placed in the proper position to receive it. Thus in Fig. 244, A B is the object, and E F the lens; the rays issuing from the two extremities and the centre of the object, are brought to a corresponding focus at a less distance on the other side of it, so as to form a distinct picture; but as the rays from A are brought to a focus at D, and those from B at C, the picture is inverted.

Fig. 244.*



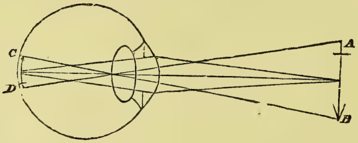
v. The further the object is removed from the lens, the nearer must the screen be brought for the formation of a distinct picture upon it, and the smaller will the picture be; and *vice versâ.*

vi. If the screen be not held precisely in the focus of the lens, but a little nearer, or further-off, the picture will be indistinct; for the rays which form it will either not have met, or they will have crossed each other.

956. The Eye, in its most perfect form—such as it possesses in Man and the higher animals,—is an optical instrument of wonderful completeness; designed to produce an exact picture of surrounding objects upon the Retina or expanded surface of the Optic nerve, by which the impression is conveyed to the brain. The rays of light which diverge from the several points of any object, and fall upon the front of the Cornea, are refracted by its convex surface whilst passing through it into the eye, and are made to converge slightly. They are brought more closely together by the Crystalline lens, which they reach after passing through the pupil; and its refracting influence, together with that produced by the Vitreous humour, is such as to cause the rays that issued from each point to meet in a focus on the Retina. In this manner a complete inverted image is formed, as shown in Fig. 245; which represents a vertical section of the eye, and the general course of the rays in its interior. As in the preceding figure, the rays which issue from the point A are brought to a focus at D; whilst those diverging from B are made to converge upon the retina at C.—The Retina, which is itself so thin as to be almost perfectly transparent, is spread over the layer of black pigment which lines the choroid coat. The purpose of this pigment is

evidently to *absorb* the rays of light that form the picture, immediately after they have passed through the retina; in this manner they are prevented from being reflected from one part of

Fig. 245.



the interior of the globe to another, which would cause great confusion and indistinctness in the picture. Hence it is that in those *albino* individuals (both of the Human race, and among the lower animals) in whose eyes this pigment is deficient, vision is extremely imperfect, except in a very feeble light; for the vascularity of the choroid and iris is such as to give to these membranes a bright red hue, which enables them powerfully to reflect the light that reaches the interior of the eye, when they are not prevented from doing so by the interposition of the pigmentary layer.

957. The Eye is so constructed as to avoid certain errors and defects to which all ordinary optical instruments are liable. One of these imperfections, termed *spherical aberration*, results from the fact that the rays of light passing through a convex lens whose curvature is circular, are *not all* brought to the same focus; those which have passed through the exterior of the lens being made to converge sooner than those which have traversed its central portion. The result of this imperfection is that the image is deficient in clearness, unless the central part only of the lens be employed.—The other source of imperfection is what is termed *chromatic aberration;* and it results from the unequal degree in which the differently-coloured rays are refracted, so that they converge towards different points. The violet rays, being the most refrangible, are soonest brought to a focus; and the red being the least refrangible, have their focus at the greatest distance from the lens. Hence it is impossible to obtain an image by an ordinary lens, in which the colours of the object are accurately represented; for the foci of its differently-coloured portions will be different, and its white rays will be decomposed, so that the outlines will be surrounded by coloured fringes.—The Optician is enabled to correct the effects of these aberrations, by combining lenses of different densities and curvatures, so arranged as to correct each others' errors, without neutralizing

the refractive power. This is precisely the plan adopted in the construction of the Eye; which, when perfectly formed, and in a healthy state, forms an accurate picture of the object upon the retina, free from either spherical or chromatic aberration. This is effected by the combination of *humours* of different densities, having curvatures precisely adapted to the required purpose.

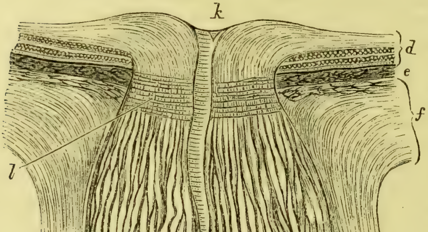
958. There are certain variations, however, in the conformation of the Eye, the occurrence of which diminishes the perfection of its result. Thus the Cornea may be too convex, and the whole refractive power too great; so that the image of an object at a moderate distance is formed *in front* of the retina, instead of *upon* it. When this is the case, a distinct image can only be formed by bringing the object nearer to the eye; the effect of which will be to throw the picture further back. Such an eye is said to be *myopic*, or 'short-sighted;' and its imperfection may be corrected by placing a concave lens in front of the cornea, of a curvature adapted to neutralize what is superfluous in the convexity of the latter.— On the other hand, if the cornea be too flat, and the refractive power of the humours be too low, the convergent rays proceeding from an object at a moderate distance will not meet *upon* the retina, but would meet *behind* it if allowed to pass-on; consequently the picture is indistinct, and it can only be made clear, either by withdrawing the object to a greater distance, which will bring the focus of the eye nearer to the front, or by interposing a convex lens to increase the refractive power of the eye. Such a condition is termed *presbyopic* (from its being common in aged persons), or 'long-sighted.' It may proceed to such an extent that not even the removal of the object to *any* distance can permit the formation of a distinct picture; so that the assistance of a convex lens must be obtained to see even remote objects clearly, though a less degree of convexity will be required than for the clear vision of nearer objects. This state is particularly well-marked after the operation for cataract; for the removal of the crystalline lens so greatly diminishes the refractive power of the eye, as to render necessary the assistance of convex lenses of high curvature; while it totally destroys the adjusting power to be next described.

959. The power by which a healthy well-formed Eye can accommodate itself to the distinct vision of objects at varying distances, is a very remarkable one. According to the laws already stated (§ 955, v. and vi.), the picture of a near object can only be distinct, when formed more remotely from the lens than the picture of a distant object. Consequently when the eye that has been looking at a distant object, and has seen it clearly, is turned to a near object, a distinct picture of the latter cannot be formed without some alteration, either in the distance between the refractive surfaces and the retina, or in the curvature of the

former. By a very refined and delicate mode of investigation, Prof. Helmholtz has succeeded in showing that the adjustment of the eye to near objects is effected by a change in the curvature of the crystalline lens; the anterior surface in particular undergoing a considerable increase in convexity, and being advanced into nearer proximity to the cornea, whilst the posterior surface has its convexity but slightly modified, and undergoes but little change of place. This alteration seems to be effected by the instrumentality of the *Ciliary muscle*, which is put in action, like the Iris, by a branch of the Third pair of nerves that passes through the Ophthalmic ganglion; and when this muscle relaxes, the lens seems to return by its own elasticity to the passive condition in which it is adapted to the vision of distant objects.

960. The various humours and containing membranes of the Eye thus answer the purpose of a most delicate and self-adjusting Optical instrument; the sole part immediately concerned in the reception of sensory impressions being the Retina, or net-like expansion of the Optic nerve, which lies between the black pigment and the vitreous humour. The Optic nerve, near its entrance into the eye (Fig. 246, *h*, *h*), divides itself into numerous small fasciculi of ultimate fibrils, which are separated

Fig. 246.*

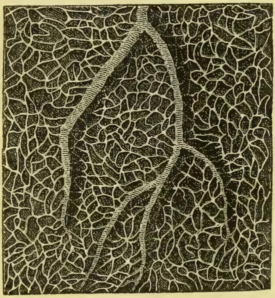


from each other by processes of the neurilemma that form what is known as the *lamina cribrosa* (*l*). After passing through this, the fasciculi appear to spread themselves out, and to inosculate

* Vertical section of the coats of the Eye, at the point of entrance of the Optic Nerve:—*d*, retina; *e*, choroid; *f*, sclerotic; *g*, sheath of the optic nerve; *h*, fibres of the optic nerve; *i*, central artery of the retina; *k*, its point of subdivision; *l*, lamina cribrosa.

with each other by an exchange of fibrils, so as to form a net-like plexus which constitutes the inner layer of the retina, or that in immediate contiguity with the vitreous humour. There is great difficulty, however, in the precise determination of the course of the nerve-fibres in the retina, on account of their minute size and the indistinctness of their characters. Externally to the stratum of nerve-fibres, which may be called the 'optic layer,' is a vesicular stratum, which consists of a finely-granular matrix, wherein are imbedded nerve-cells closely resembling those of the Encephalon, and having like them a variable number of processes, some of which appear to become continuous with the peculiar fibres about to be described. It is to these fibrous and vesicular layers of the Retina, which together make-up the analogue of the cortical substance of the Cerebrum (§ 378), that the principal supply of blood is distributed by the minute capillary network (Fig. 247) which is spread-out through their substance;

Fig. 247.*



this having its origin in the ramifications of the *Arteria centralis retinæ*, which passes to the eye-ball through the centre of the optic nerve (Fig. 246, *i k*).—The principal part of the thickness of the Retina, however, is made-up of a series of layers (altogether forming 'Jacob's membrane'), which are chiefly composed of elongated 'rods' terminating in 'cones', so that the whole may be termed the 'bacillar' or staff-like structure. The general direction of these rods is *radial* as regards the globe of the eye, or *vertical* as regards any part of the surface of the membrane; yet there are situations in which the staff-like bodies

* Distribution of Capillaries in vascular layer of Retina.

are directed so obliquely, as to present quite an imbricated arrangement upon the external surface of the retina. Although the nature of the bacillar layer has not been yet fully elucidated, yet there appears adequate reason for regarding it as forming part of the true nervous structure, and as essentially concerned in the reception of sensory impressions. In the 'yellow spot of Soemmering,' which is situated in the exact centre of the retina, and is undoubtedly its most sensitive part, the layer of nerve fibres derived from the optic nerve is entirely wanting, the retina being composed of the vesicular and bacillar layers alone. On the other hand, at the point at which the optic nerve enters the eye, the thickness of the retina is entirely made-up of the fibrous layer, the vesicular and bacillar layers being wholly deficient; and it can be shown by a simple experiment that this spot of the retina is insensible to visual impressions made upon it alone. Hence it is obvious that these impressions cannot act upon the nerve-fibres, save through the intermediation of the vesicles; and there seems much probability in the supposition of Prof. Kölliker, that the 'rods' and 'cones' are nervous elements which are primarily concerned in the reception of luminous impressions, and that they communicate their condition to the vesicles by means of their delicate fibrous prolongations, and thence to the fibres of the optic nerve.—For the maintenance of the due nutrition of this apparatus, it is requisite that it should be occasionally called into use. If its functional power be destroyed by opacity of the anterior portion of the eye, the nutrition of the retina and optic nerve suffers to such a degree, that these parts cease after a time to exhibit their characteristic structure; thus showing that the general rules already stated (Chap. viii.) in regard to the connection between the functional activity and the due nutrition of tissues and organs, hold good with respect to the Nervous substance.

961. The picture of external objects which is formed upon the Retina, closely resembles that which we see in a Camera Obscura. It represents the outlines, colours, lights and shades, and relative positions, of the objects before us; but these do not necessarily convey to the mind the knowledge of their real forms, characters, or distances. The perception of the latter, as already remarked (§ 936), is a *mental* process; and it may be *intuitive*, or *acquired*, —the latter, it would seem, being the general condition of the function in Man, the former in the lower animals. The infant is educating his perceptive powers, long before any indications present themselves of the exercise of higher mental faculties. By the combination, especially, of the sensations of Sight and Touch, he is learning to judge of the surfaces of objects as they *feel*, by the *appearances* they present,—to form an idea of their *distance*, by the mode in which his eyes are directed towards them,—and

to estimate their *size*, by combining the notions obtained through the picture on the retina with those he acquires by the movement of his hands over their different parts.—A simple illustration will show how closely the ideas excited by the two sets of sensations are blended in our minds. The idea of *smoothness* is one which has reference to the touch, and yet it constantly occurs to us on looking at a surface which reflects light in a particular manner: on the other hand, the idea of *polish* is essentially visual, having reference to the reflection of light from the surface of the object; and yet it would occur to us from the sensation conveyed through the touch, even in the dark.

962. That this sort of combination is not intuitive, in Man, but is the result of experience, is evident from the numerous observations that have been made upon individuals who had acquired the sense of Sight for the first time, after long familiarity with the characters of objects as perceived through the Touch. Thus a boy of four years old, upon whom the operation for congenital cataract had been very successfully performed, continued to find his way about his father's house rather by *feeling* with his hands, as he had been formerly accustomed to do, than by his newly-acquired sense of sight; being evidently perplexed, rather than assisted, by the sensations which he derived through this. But when learning a new locality, he employed his sight, and evidently perceived the increase of facility which he derived from it. Among the many interesting particulars recorded of the youth on whom Cheselden operated with equal success, it is mentioned that although perfectly familiar with a *dog* and a *cat* by feeling them, and quite able to distinguish between them by his sight, it was long before he associated his *visual* with his *tactile* sensations, so as to be able to name either animal by sight alone.—The question was put by Locke, whether a person born blind, who was able by his touch to distinguish a cube from a sphere, would, on suddenly obtaining his sight, be able to recognize each by the latter sense; the reply was given in the negative; and the experience of the cases just referred to, as well as of many others, fully justifies such an answer.

963. The recognition of the erect position of objects notwithstanding the inversion of their picture on the retina (the cause of which has been a fruitful source of discussion) is attained through the general *Sense of Direction*, in virtue of which we derive from the retinal picture an idea of the relative positions of objects, corresponding to that which we obtain through the sense of Touch. The difficulty which has been raised on the subject of 'erect vision' is rather apparent than real: being founded on an erroneous idea of the nature of the visual sense. For it seems to have been supposed that we *look at* the retinal picture with the 'mind's eye,' just as we look at a picture in a camera with the

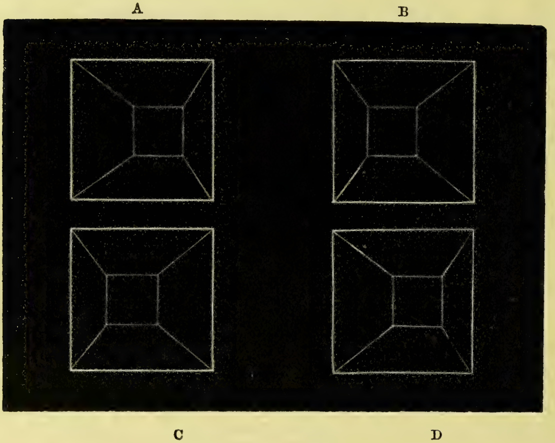
bodily eye; whereas the fact is clearly that the visual perception is not a mere transfer of the physical impression, but is a mental state excited by it. And it has been forgotten that the retinal picture is reversed *horizontally* as well as *vertically;* so that objects on the right hand are pictured on the left, and *vice versâ.* Now if the sensibility of a certain spot of the retina be excited by mechanical pressure (§ 933), the luminous spectrum or *phosphène* which is produced will be seen in the direction of a line passing from the excited spot through the centre of the crystalline lens (or thereabouts); and, in like manner, it can be shown by mathematically projecting the course of the rays from an external object through the eye, according to the refractive powers of its different parts, that lines drawn from the several points of the object to the corresponding points of its picture on the retina all pass through this common 'centre of direction.' Thus it appears that we infer the relative directions of objects seen in one view from the relation of the several points of the retinal picture to the centre of direction; so that, as all the lines of direction cross each other both horizontally and vertically, the formation of the reversed picture on the retina suggests to our minds the representation of the objects in their true relative positions. Whether this suggestion acts *intuitively*, that is, in virtue of our original mental constitution, or whether it is *acquired by experience* in early infancy, cannot be positively stated; but there is strong ground for believing that in this as in other matters, the visual sense is educated through the tactile. It is probable, moreover, that much assistance is derived, in estimating the relative positions of objects not combined in the same picture, by the indications of the muscular sense as to the *direction of movement* of the eyes, when their axes are brought to bear upon these objects in succession.

964. The same may be said of the cause of the *singleness* of the sensation perceived by the mind, although an image is formed upon the retina of each eye, of those objects at least, which lie in the field of vision that is common to both. This blending of the pictures formed upon the two retinæ into a single perception, appears to be, in part at least, the effect of habit. For when the images do not fall upon those parts of the two retinæ which are accustomed to act together, *double vision* is the result. Thus if, when looking steadily at an object, we press one of the eye-balls sideways with the finger, we see two representations of the object; and the same thing frequently occurs as a result of an affection of the nerves or muscles of one or both eyes, as in ordinary *strabismus* or squinting, or from some derangement in the nervous centres, as in various disorders of the Encephalon, and in intoxication. If this condition should be permanent, however, we usually find that the individual becomes accustomed to the double images,

or rather ceases to perceive that they *are* double ; probably because the mind becomes habituated to receive the impressions from the two parts of the retinæ which *now* act together. And if, after the double vision has passed away, the conformity of the two eyes be restored (as by the operation for the cure for squinting), there is double vision for some little time, although the two parts of the retina which originally acted together are now brought into their pristine position.—But the images thus combined are far from being identical; and one of the most remarkable of all our perceptions, which, if not absolutely intuitive, is acquired at a very early period, is that by which they are reconciled and combined, and caused to give rise to an idea that differs from that suggested by either image. No near object *can* be seen by the two eyes in the same manner; of this the reader may easily convince himself, by holding-up a thin book in such a position that its back shall be in a line with the nose and at a moderate distance from it; and by looking at the book, first with one eye, and then with the other. He will find that he gains a different view of the object with each eye, when used separately; so that if he were to represent it as he actually sees it under these circumstances, he would have two perspective delineations differing from one another because drawn from different points of view. But on looking at the object with the two eyes conjointly, there is no confusion between these pictures; nor does the mind dwell upon either of them singly; but the union of the two gives us the definite conception of a solid *projecting* body, such as we could only have otherwise acquired by the exercise of the sense of Touch. That this is really the case has been proved by experiments with the very ingenious instrument, the Stereoscope, invented by Prof. Wheatstone; which is so contrived as to bring to the two eyes, either by reflection from mirrors or by refraction through prisms or lenses, two different pictures, such as would be accurate representations of a solid object as seen by the two eyes respectively. When the arrangement is such as to bring the images of these pictures to those parts of the retinæ which would have been occupied by the images of the solid (supposing *that* to have been before the eyes), the mind will perceive, not one or other of the single representations of the object, nor a confused union of the two, but a body projecting in *relief*, the exact counterpart of that from which the drawings were made.—Thus in Fig. 248 the upper pair of pictures, A, B, when combined in the stereoscope, suggest the idea of a *projecting* truncated pyramid, with the small square in the centre, and the four sides sloping equally *away from* it; whilst the lower pair C, D, which are the same as the upper, but transferred to the opposite sides, no less vividly bring to the mind the visual conception of a *receding* pyramid, still with the small square in the centre, but the four sides sloping equally *towards* it.

965. When two pictures representing *dissimilar* objects are projected upon the retinæ of the two eyes by means of the Stereoscope, the result is a curious one. The mind perceives only one of them, the other being completely excluded for a time; but it

Fig. 248.



commonly happens that after one has been seen for a short period, the other begins to attract attention and takes its place, the first entirely disappearing; so that there is no confusion or intermingling of images, except at the moment of change. The Will may determine, to a certain extent, which object shall be seen; but not entirely; for if one picture be more illuminated than the other, it will be seen during a larger proportion of the time.—An interesting variation of this experiment may be made, without the aid of the Stereoscope, by holding a piece of blue glass before one eye, and a piece of yellow glass before the other. The result will usually be, not that everything will be seen of a green colour, but that the surrounding objects will be seen alternately blue and yellow; or sometimes the field of vision will be blue spotted with yellow, alternating with yellow spotted with blue. Thus, when we have two dissimilar objects before the eyes, our attention cannot be kept upon either to the exclusion of the other, but is involuntarily directed, either in part or completely, to one and the other alternately.

966. Our idea of the *distance* of near objects is evidently

acquired from experience; and is suggested by the muscular sensations which are produced by the contraction of the adductor muscles of the eyes in bringing them to converge upon it (§ 968), aided perhaps by those derived from the contraction of the ciliary muscle in the focal adjustment of the crystalline lens (§ 959). When we direct our eyes towards a near object, a certain degree of convergence takes-place between their axes; the degree increasing as the distance between the object and the eyes diminishes, and *vice versâ*. We instinctively interpret the sensations thus produced, in such a manner as to be able to compare, with great accuracy, the relative distances of two objects that are not remote from the eyes. This intuition, however, is evidently one of the *acquired* kind; as may be seen by watching the actions of an infant, or of a person who has recently become possessed of Vision. When an object is held before the eyes, and an attempt is made to grasp it, the manner in which the attempt is made clearly shows that there is no power of forming a precise idea of its situation, such as that which exists in many of the lower animals from their first entrance into the world (§ 938). The impressions made upon the eyes have to be corrected by those received through the Touch, before the power of judging of distance is acquired. How much this power depends upon the conjoint use of *both* eyes, is evident from the difficulty with which any actions that require an exact appreciation of distance are performed by those who have lost the sight of one eye, until they have acquired new modes of judging of it.—In regard to remote objects we have not the same guide; since the convergence of the eyes in viewing them is so slight, that the axes are virtually parallel. Our judgment of *their* distance is chiefly founded upon their apparent size, if their actual size be known to us; and also upon the extent of ground which we see to intervene between ourselves and the object. But if we do not know their actual size, and are so situated that we cannot estimate the intervening space, we form our judgment chiefly from the greater or less distinctness of their colour and outline. Hence our idea of it will be very much affected by varying states of the atmosphere; a slight haziness increasing the apparent distance, whilst a peculiarly clear state of the air will cause remote objects to seem to approach much more closely. This want of convergence between the axes of the two eyes has the further effect of causing the pictures upon the two retinæ to be nearly identical; and consequently the idea of *projection* is not so strongly excited, nor are we able to distinguish with the same certainty between a well-painted picture, in which the lights and shades are preserved, and the objects themselves in relief.

967. Our notion of the *size* of an object is closely connected with that of its distance. It is founded upon the dimensions of the picture projected on the retina; and the dimensions of this

picture will vary, according to the laws of optics (§ 955, v.), inversely as the distance,—being, for example, twice as great when the object is viewed at the distance of one foot, as when it is carried to the distance of two feet. When we know the relative distances of two objects, the estimation of their real comparative sizes from their *apparent* sizes is easily effected by a simple process of mind; but this is not the case when we only guess at their distances; and our estimate of the size of objects even moderately remote, is as much affected by states of the atmosphere as is that of their distance, — the one being, in fact, proportional to the other. Thus a slight mist which gives the idea of increased distance, will also augment the apparent size; because in order that an object two miles off should produce a picture upon the retina of the same extent as that made by an object one mile off, it must have double the dimensions. It is evident that our perception of the size of objects must be *acquired* by experience, in the same manner as that of their distance has been shown to be.

968. The Movements of the Eyeball are effected by the four *Recti* and two *Oblique* muscles; and much discussion has taken place in regard to their functions. There can be no doubt that the Eyeball may be caused to rotate not merely upwards, downwards, inwards, and outwards, but in any intermediate direction, by the agency of the Recti either separately or in binary combination. But it has been felt difficult to explain the *harmonious* movements of the two eyes, when, as commonly happens, the *internal* recti are put in action on one side and the *external* on the other. All difficulty disappears, however, when we look at these movements as performed under the guidance of visual sensations under the mandates of the Will; since in no case, as already explained (§ 923), does Volition do more than *determine the result*, which the automatic apparatus works out under the guidance of sensations: so that the speciality of the movements of the Eye consists only in this, that the sensations which guide them are not those received from the muscles put into action, but from the organ they have to move. When we raise or lower our eyes to look at some object above or below their level, we use in the one case the two superior, in the other the two inferior recti; but when we turn them to one side or the other, we use the external rectus of one eye in combination with the internal rectus of the other. When, on the other hand, we make the axes of our eyes converge upon a near object placed in front of us, we put the two internal recti into action together; and by gradually approximating the object, we can make this convergence increase until it becomes a decided squint. But by an appropriate arrangement of mirrors or prisms, and by steadily fixing our eyes upon the image of an object presented by these, we can put the two external recti into conjoint action, so as to

produce a divergent squint; and it is possible, by similar means, to make the superior rectus of one eye act with the inferior rectus of the other. How purely automatic is the essential nature of these movements, is shown by the following simple experiment: —let the reader continue to look steadily at an object placed straight before him, while he *turns* his head on its vertical axis from side to side, or *nods* on its transverse axis either upwards or downwards, the eyeballs will *roll* in their orbits in the contrary direction *without any consciousness* of the movement on his own part, so as to keep the image of the object upon the central part (the most sensitive spot) of the retina.—It has now been clearly proved experimentally that the function of the two *oblique* muscles is to rotate the eye upon its longitudinal axis; and that this movement is performed, unconsciously to ourselves, whenever we *incline* the head to one side or the other. The effect of this movement would be to disturb the picture on the retina, not by changing its place, but (so to speak) by twisting it round; and this *twist* is antagonized by a twist of the eye in the opposite direction, just as, in the previous cases, the change of place of the picture was antagonized by the roll of the eye in the opposite direction.—Further, if we completely exclude all light from the eyes, we find it difficult to move them at all, the ordinary guiding sensations being in abeyance; and the effort produces an uncomfortable feeling of strain in the muscles. In persons who are so completely blind as to have no consciousness even of light, especially in children born in that state who have never acquired the habit of symmetrical movement, the want of consentaneous motion of the Eyes is often very remarkable.

969. We have now to consider briefly some other phenomena of Vision, in which the acts of Mind that have been just alluded to do not participate.—The *contraction* of the Pupil under the stimulus of light, effected by a sphincter muscle which surrounds the aperture in the Iris, is an action with which the *will* has nothing to do; and it takes-place entirely without our consciousness. Although it is due to the stimulus of light, yet there is reason to believe that the consciousness of the presence of light is not requisite; and that it is, therefore, an excito-motor action. The Optic nerve seems to be the channel through which the impression is conveyed to the nervous centres, whilst the Third pair is that through which the motor impulse is conveyed to the iris, its filaments passing, however, through the Ophthalmic ganglion: but there is some ground for the belief that the Fifth pair may in some degree convey the requisite stimulus, when the optic nerve has been divided.—That the *dilatation* of the pupil is a muscular action, appears from the fact that the *radiating* fibres of the iris are of the same character with the *circular;* both sets constituting, in Man, a peculiar variety of the non-striated form

of muscular tissue. The stimulus to this action is conveyed through the branches of the Sympathetic system which pass through the ophthalmic ganglion; and by the division of the sympathetic of either side high up in the neck, a permanent contraction of the pupil is induced, a temporary dilatation being effected by a galvanic stimulus to the upper or cephalic extremity of the divided sympathetic trunk.*—The contraction of the pupil is evidently destined to exclude from the interior of the eye such an amount of light as would be injurious to it; whilst its dilatation in opposite circumstances admits the greatest possible number of rays. There is a contraction of the pupils, however, which takes-place without any change in the amount of light. This occurs when the two eyes are made to converge strongly upon any object brought very near them; and its purpose appears to be, to prevent the rays from entering the eye at such a wide angle, as would render it impossible for them to be all brought to their proper foci, and would thus produce an indistinct image.

970. In the use of the Eye, like that of the Ear, there is a tendency to blend into one continuous image a succession of luminous impressions made at short intervals; upon which fact depend a number of curious optical illusions. The length of the greatest interval that can elapse without an interruption of the presence of the image (in other words the duration of the visual impression), may be measured by causing a luminous object to whirl round, and by ascertaining the longest period that may be allowed for each revolution, consistently with the completeness of the circle of light thus formed. By experiments of this kind, the time has been found to vary in different individuals, or in different states of the same individual, from about 1-4th to 1-10th of a second; that is, the impression must be repeated from four to ten times in each second, to ensure the continuousness of the image.

971. The impressions of variety of *colour* are produced by the differently-coloured rays which objects reflect or transmit to the eye. It is curious that some persons, whose sight is perfectly good for forms, distances, &c., are unable to discriminate colours. This curious affection has received the name of Daltonism, from the circumstance that the celebrated Dalton was an example of it. There are numerous modifications of it; the want of power to discriminate colour being total in some, whilst in others it extends only to certain shades of colour, or to the complementary colours.

972. When the retina has been exposed for some time to a strong impression of some particular kind, it seems less susceptible to feebler impressions of the same kind; thus if we look at any *brightly-luminous* object, and then turn our eyes upon a sheet of

* There is a doubt whether these actions are occasioned by the direct influence of the Sympathetic nerve on the muscular fibres of the Iris, or are consequent upon the affection of the sensibility of the Retina which is produced by its *vaso-motor* influence (§ 928).

paper, we shall perceive a *dark* spot upon it; the portion of the retina which had received the brighter image not being affected by the fainter one.—Again, when the eyes have received a strong impression from a *coloured* object, the spot which is seen when the eyes are directed upon a white surface exhibits the *complementary* colour; for the retina has been so strongly affected, in the part that originally received the image, by its vivid hue, that it does not perceive the fainter hue of the same kind in the object to which it is then turned, and is impressed only by the remaining rays forming the complementary colours. This explanation applies to the phenomena of the coloured shadows which are often seen at sunset, and of those which may be seen in a room whose light enters through coloured glass or drapery. For if the prevailing light be of one colour,—orange or red for instance, —the eye will not take cognizance of that colour in the faint light of the shadows; and will see only its complement, blue or green. If the shadow be viewed through a tube, in such a manner that the general coloured ground is excluded, it presents the ordinary tint.

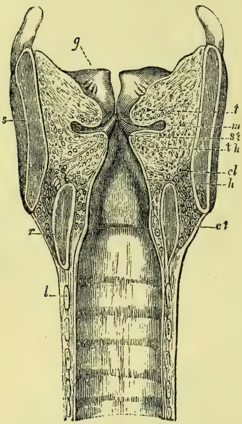
CHAPTER XV.

OF THE VOICE AND SPEECH.

973. There is one particular application of Muscular power in Man, which deserves special consideration, as being that by which he effects his most complete and intimate communication with his fellows;—that, namely, by which his organ of *Voice* is put into action. In all air-breathing Vertebrata, the production of sound depends upon the passage of air through a certain portion of the respiratory tubes, which is so constructed as to set it in vibration as it passes-forth from the lungs.—In Reptiles, the vibrating apparatus is situated at the point where the trachea opens into the front of the pharynx; it is of very simple construction, however, being only composed of a slit bounded by two contractile lips; and few of the animals of this class can produce any other sound than a *hiss*, which, owing to the great capacity of their lungs, is often very much prolonged.—In Birds, the situation of the vocal organ is very different. The trachea opens into the front of the pharynx, as in Reptiles, by a mere slit; the borders of which have no other movement than that of approaching one another, so as to close the aperture when necessary. This appears to be the instrument for regulating the ingress and egress of air, in conformity with the wants of the *respiratory* function. The *vocal* larynx of Birds is situated at the lower extremity of the trachea, just where it subdivides into the bronchial tubes; and it is of very complex construction, especially in the singing birds.—

In Mammalia, on the other hand, the vocal organ and the regulator of the respiration are united in one larynx, which is situated at the top of the trachea. There are few, if any, of this class, which have not some vocal sound; but the variety and expressiveness which can be given to it, differ considerably in the several orders; being by far the greatest in Man, who, alone, there is reason to believe, has the power of producing articulate sounds, or proper *language*.

Fig. 249*.

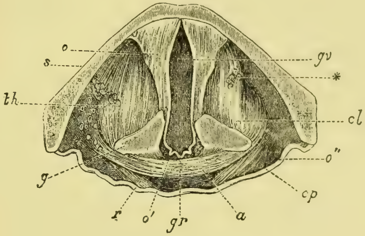


974. The Larynx is built-up, as it were, upon the *Cricoid* cartilage (Figs. 249, 250, *r*), which surmounts the trachea, and which might be considered as its highest ring modified in form, its depth from above downwards being much greater posteriorily than anteriorily. This is embraced, as it were, by the Thyroid cartilage (*s*); which is articulated to the sides of the Cricoid by its lower horns, round the extremities of which it may be considered to rotate, as on a pivot. In this manner the front of the *Thyroid* cartilage may be lifted up or depressed by the muscles which act upon it, whilst the position of its posterior part is but little changed. Upon the upper surface of the back of the Cricoid cartilage, are seated the two small *Arytenoid* cartilages (*g*); these are so tied to the cricoid by a bundle of strong ligaments, as to have a sort of rotation upon an articulating surface, which enables them to be approximated-to or separated-from each other; their inner edges being nearly parallel in the first case, but slanting away from each other in the second. To the anterior points of these cartilages are attached the *Chordæ vocales* or vocal ligaments (*s t*), composed of yellow fibrous or elastic tissue. These stretch across to the front of the Thyroid cartilage; and it is upon their condition and relative situation, that the absence or the production of vocal tones, and all their modifications of pitch, depend. They are

* Vertical section through the middle of the Human Larynx, in a direction transverse to that of the vocal cords:—*l*, rings of the trachea; *r*, cricoid cartilage; *s*, thyroid cartilage; *g*, arytenoid cartilage; *t*, superior or false vocal cords; *m*, ventricle of the larynx; *st*, inferior or true vocal cords; *th*, thyro-arytenoideus muscle; *cl*, crico-arytenoideus lateralis; *ct*, crico-thyroideus; *h*, mucous membrane lining the larynx.

rendered tense by the depression of the front of the Thyroid cartilage, and relaxed by its elevation; by which action the *pitch* of the tones is regulated.

Fig. 250.*



975. During the ordinary acts of inspiration and expiration, the Chordæ vocales appear to be widely separated from each other, and to be in a state of the freest possible relaxation. In order to produce a vocal sound, not only must they be made to approach one another, but their inner faces must be brought into parallelism, both of which ends are accomplished by the rotation of the Arytenoid cartilages; whilst, at the same time, they must be put into a certain degree of tension, by the depression of the Thyroid cartilage. Both of these movements take place consentaneously, and are mutually adapted to each other; the vocal ligaments being approximated, and the rima glottidis consequently narrowed, at the same time that their tension is increased. There is a certain aperture which is favourable to the production of each tone, although the pitch itself is governed by the tension of the Vocal Cords; and it is, perhaps, to a want of consent between the two, that the peculiarly discordant nature of some voices, which appear incapable of producing a distinct musical tone, is due.— Even when the edges of the vocal cords are most closely approximated, as in the production of a high note, the posterior part of the rima glottidis (Fig. 250, *g r*) remains nearly as open as it is when the cords are separated from each other so as to widen the anterior part of the fissure; and hence it appears that

* Transverse section of the Larynx just above the Vocal Cords and the bases of the Arytenoid Cartilages:—*o*, *o'*, *o''*, mucous surface of the glottis; *r*, cricoid cartilage; *s*, thyroid cartilage; *g*, arytenoid cartilage; *th*, thyro-arytenoideus muscle; *a*, arytenoideus transversus; *cp*, crico-arytenoideus posticus; *cl*, crico-arytenoideus lateralis; *, divided fibres of the thyro-epiglotticus; *g v*, vocal glottis; *g r*, respiratory glottis.

the anterior portion of the glottis (*g v*) is especially subservient to vocalization, and the posterior (*g r*) to respiration.

976. Thus there are two sets of movements concerned in the act of vocalization;—the regulation of the relative position of the Vocal Cords, which is effected by the movements of the Arytenoid cartilages;—and the regulation of their tension, which is determined by the movements of the Thyroid cartilages. The Arytenoid cartilages are made to diverge from one another by means of the *Crico-arytenoidei postici* of the two sides (*c p*), which proceed from their outer corners and turn somewhat round the edge of the Cricoid, to be attached to the lower part of its back; their action is to draw the outer corners of the Arytenoid cartilages outwards and downwards, so that the points to which the vocal ligaments are attached are separated from one another, and the rima glottidis is thrown open. The action of these muscles is antagonized by that of the *Arytenoideus transversus* (*a*), which draws-together the Arytenoid cartilages; and by that of the *Crico-arytenoidei laterales* of the two sides (*c l*), which run forwards and downwards from the outer corners of the Arytenoid cartilages, and tend by their contraction to bring-together their anterior points, to which the Vocal ligaments are attached.—The depression of the front of the Thyroid cartilage, and the consequent tension of the Vocal ligaments, are occasioned by the conjoint action of the *Crico-thyroidei* (*c t*) of the two sides, which causes the Thyroid and Cricoid cartilages to rotate the one upon the other, at the articulation formed by the inferior cornua of the former; and this action will be assisted by the *Sterno-thyroidei*, which tend to depress the front of the Thyroid cartilage, by pulling from a fixed point below. On the other hand, the elevation of the front of the Thyroid cartilage, and the relaxation of the Vocal ligaments, are effected by the contraction of the *Thyro-arytenoidei* of the two sides (*th*), whose attachments are the same as those of the Vocal ligaments themselves; and this is aided by the *Thyro-hyoidei*, which will tend to draw-up the front of the Thyroid cartilage, acting from a fixed point above.—Over none of these muscles has the Will any immediate control; but their actions are brought about, like those of other so-called Voluntary muscles, by *willing a result* previously conceived in the mind, under the guidance of Auditory sensations (§ 905).

977. The muscles which govern the aperture of the Glottis,—those namely, which separate and bring-together the arytenoid cartilages, and thus widen or contract the space between the posterior extremities of the vocal ligaments,—have important functions in connection with the Respiratory actions in general; standing as guards, so to speak, at the entrance to the lungs. We can entirely close the glottis through their means, by an effort of the Will, either during inspiration or expiration; and it is a spasmodic

movement of this sort which is concerned in the acts of Coughing and Sneezing, the purpose of which is to expel, by a sudden and powerful blast of air, any irritating substances, whether solid, liquid, or gaseous, which have found their way into the air passages. These muscles appear to be under the sole direction of the *inferior* or *recurrent* laryngeal nerve, which seems to possess exclusive *motor* endowments. When this nerve is divided on each side, or when the Par Vagum is divided above its origin, the muscles of the larynx (with the exception of the crico-thyroid) are paralyzed; and the aperture of the glottis may remain open, or may be entirely closed, according to the manner in which its lips are affected by the currents of air in egress or ingress. It is found that, under such circumstances, *tranquil* respiration may be carried-on; but that any violent ingress or egress of air will tend to drive the lips of the glottis (these being in a state of complete relaxation) into apposition with each other, so as completely to close the aperture. The character of the *superior* laryngeal nerve appears to be almost exclusively *afferent;* no muscle, except the crico-thyroid, being thrown into contraction when it is irritated; whilst, on the other hand, if it be divided, neither the act of coughing, nor any reflex respiratory movement whatever, can be excited by irritating the lining membrane of the larynx.

978. It has been fully proved, by the researches of Willis, Müller and others, that the action of the Vocal ligaments in the production of sound bears no resemblance to that of vibrating *strings;* and that it is not comparable to that of the mouth-piece of the *flute*-pipes of the Organ: but that it is, in all essential particulars, the same with that of the *reeds* of the Hautboy or Clarionet, or the *tongues* of the Accordion or Concertina. All the phenomena attending the production of Musical tones are fully explicable on this hypothesis; except the production of *falsetto* notes, which has not yet been clearly accounted-for. It has been supposed by some that these are flute-notes, formed by the vibrations of the column of air to which the rima glottidis then serves as the embouchure; but from observations made by means of the Laryngoscope upon the state of the glottis in a person giving forth falsetto tones, it appears that the difference between these and the 'chest' notes essentially consists in the want of approximation of the *surfaces* of the vocal cords which takes place when the latter are produced (§ 975), their *edges* only being brought together for the falsetto, by an approximation of the Arytenoid cartilages without rotation.— The power which the Will possesses, of determining, with the most perfect precision, the exact degree of tension which these ligaments shall receive, is extremely remarkable. Their average length in the Male, in the state of repose, is estimated by Müller at about 73-100ths of an

inch; whilst, in the state of greatest tension, it is about 93-100ths; the whole difference, therefore, is not above 20-100ths, or one-fifth, of an inch. In the female glottis, their average dimensions are about 51-100ths and 63-100ths, respectfully; so that the difference is here only 12-100ths, or less than one-eighth, of an inch. Now the natural compass of the voice, in most persons who have cultivated the vocal organ, may be stated at about two octaves, or 24 semitones. Within each semitone, a singer of ordinary capability could produce at least ten distinct intervals; so that, for the total number of intervals, 240 is a very moderate estimate. There must, therefore, be at least 240 different states of tension of the vocal cords, every one of which can be at once determined by the Will, when a distinct conception exists of the tone to be produced (§ 905); and as the whole variation in their length is not more than one-fifth of an inch, even in Man, the variation required to pass from one interval to another, will not be more than 1-1200th of an inch.—And yet this estimate is much below that which might be truly made from the performance of a practised vocalist. The celebrated Madame Mara is said to have been able to sound 50 different intervals between each semitone, and the compass of her voice was at least 40 semitones, so that the total number of intervals was 2000. The extreme variation in the length of the vocal cords, even taking the larger scale of the Male larynx, not being more than one-fifth of an inch, it may be said that she was able to determine the contractions of her vocal muscles to the *ten-thousandth* of an inch. This power primarily depends upon the discrimination which can be exercised by the Auditory sense; and secondarily on the degree of exactness in the regulation of the muscular movements, which may be attained by practice under its guidance.

979. It is on account of the greater length of the Vocal cords, that the *pitch* of the voice is much lower in Man than in Woman; but this difference does not arise until the end of the period of childhood; the size of the larynx being about the same in the Boy and Girl up to the age of 14 or 15 years, but then undergoing a rapid increase in the former, whilst it remains nearly stationary in the latter. Hence it is that Boys, as well as Girls and Women, sing either *treble* or *alto;* whilst Men sing *tenor*, which is about an octave lower than the treble, or *bass*, which is about an octave lower than the alto. The cause of the variation in the *timbre* or *quality* in different voices, is not certainly known; but it appears to be due, in part, to differences in the degree of flexibility and smoothness of the cartilages of the larynx. In women and children, these cartilages are usually soft and flexible; and the voice is clear and smooth; whilst in men, and in women whose voices have a masculine roughness, the cartilages are harder, and are sometimes almost completely ossified. The

loudness of the voice depends in part upon the force with which the air is expelled from the lungs; but the variations in this respect which exist among different individuals, seem partly due to the degree in which its resonance is increased by the vibration of the other parts of the larynx and of the neighbouring cavities. In the Howling Monkeys of America, there are several pouches opening from the larynx, which seem destined to increase the volume of tone that issues from it; one of these is excavated in the substance of the hyoid bone itself. Although these Monkeys are of inconsiderable size, yet their voices are louder than the roaring of lions, and are distinctly audible at the distance of two miles; and when a number of them are congregated together, the effect is terrific.

980. The vocal sounds produced by the action of the Larynx are of very different characters; and may be distinguished into the *cry*, the *song*, and the ordinary or acquired *voice*. The cry is generally a sharp sound, having little modulation or accuracy of pitch, and being usually disagreeable in its *timbre* or quality. It is that by which animals express their unpleasing emotions, especially pain or terror; and the Human infant, like many of the lower animals, can utter no other sound.—In *song*, by the regulation of the vocal cords, definite and sustained musical tones are produced, which can be changed or modulated at the will of the individual. Different species of Birds have their respective songs; which are partly instinctive, and partly acquired by education. In Man, the power of song is entirely acquired; but some individuals possess a much greater facility in acquiring it than others, —this superiority appearing to depend upon their more precise conception of the tones to be sounded, as well as their more ready imitation, independently of differences in the construction of the larynx itself. The larynx of an accomplished vocalist, obedient to the expression of the emotions, as well as to the dictates of the will, may be said to be the most perfect musical instrument ever constructed.—The *voice* is a sound more resembling the cry, in regard to the absence of any sustained musical tone; but it differs from the cry, both in the quality of its tone, and in the modulation of which it is capable by the will. In ordinary conversation, the voice passes through a great variety of musical tones, in the course of a single sentence or even a single word, sliding imperceptibly from one to another; and it is when we attempt to fix it definitely to a certain pitch, that we change it from the *speaking* to the *singing* tone.

981. The power of producing *articulate* sounds, from the combination of which *Speech* results, is altogether independent of the Larynx; being due to the action of the muscles of the mouth, tongue, and palate. Distinctly-articulate sounds may be produced without any vocal or laryngeal tone, as when we *whisper;* and it

has been experimentally shown that the only condition necessary for this mode of speech, is the propulsion of a current of air through the mouth from back to front. On the other hand, we may have the most perfect laryngeal tone without any articulation; as in the production of musical sounds not connected with words. But in ordinary speech, the laryngeal tone is modified by the various organs which intervene between the larynx and the os externum. The simplest of these modifications is that by which the *Vowel* sounds are produced; these sounds being continuous tones, modified by the form of the aperture through which they pass-out. Thus, let the reader open his mouth to the widest dimensions, depress the tongue, and raise the velum palati, so as to make the exit of air as free as possible; on then making a vocal sound, he will find that this has the character of the vowel *a* in *ah*. On the other hand, if he draw-together the lips, still keeping the tongue depressed, he will pass to the sound represented in the English language by *oo*, in the Continental language by *u*. By attention to the production of other vowel sounds, it will be found that they are capable of being formed by similar modifications in the form of the buccal cavity and the size of the buccal orifice; and that they are capable of being sustained for any length of time. There is an exception, however, in regard to the sound of the English *i*, as in *fine;* which is, in reality, a diphthongal sound, produced in the act of transition from a peculiar indefinite murmur to the sound of the long *e*, which takes its place when we attempt to continue it. The short vowel sounds, moreover, such as *a* in *fat*, *e* in *met*, *o* in *pot*, &c., are not capable of being perfectly prolonged; as they require, for their true enunciation, to be immediately followed by a consonant.—A tolerably-good artificial imitation of Vowel sounds has been effected by means of a reed-pipe representing the larynx, surmounted by an India-rubber ball, with an orifice, representing the cavity and orifice of the mouth. By modifying the form of the ball, the different vowels can be sounded during the action of the reed.

982. In the production of the sounds termed *Consonants*, the breath suffers a more or less complete interruption in its passage through the parts anterior to the larynx. The most natural primary division of these sounds, is into those which require a total stoppage of the breath at the moment previous to their being pronounced, and which, therefore, cannot be prolonged; and those in pronouncing which the interruption is partial, and which can, like the vowel-sounds, be prolonged indefinitely. The former have received the designation of *explosive* consonants; the latter are termed *continuous*.—In pronouncing any consonants of the *explosive* class, the posterior nares are completely closed; and the whole current of air is directed through the mouth. This may be checked

by the approximation of the lips, as in pronouncing *b* and *p;* by the approximation of the point of the tongue to the front of the palate, as in pronouncing *d* and *t;* or by the approximation of the middle of the tongue to the arch of the palate, as in pronouncing the hard *g* or *k*. The difference between *b*, *d*, and *g*, on the one hand, and *p*, *t*, and *k*, on the other, depends simply upon the greater extent of the meeting surfaces in the former case than in the latter.—In sounding some of the *continuous* consonants, the air is not allowed to pass through the nose; but the interruption in the mouth is incomplete; this is the case with *v* and *f*, *s* and *z*. In others, the posterior nares are not closed, and the air has a nearly free passage, either through the nose alone, as in *m* and *n*, or through the nose and mouth conjointly, as in *l* and *r*. The sound of *h* is a mere aspiration, caused by an increased force of breath; and that of the guttural *ch*, as it exists in Welsh, Gaelic, and most Continental languages, is an aspiration modified by the elevation of the tongue, which causes a slight obstruction to the air, and an increased resonance in the back of the mouth.

983. The study of the mode in which the different Consonants are produced, is of particular importance to those who labour under defective speech, especially that difficulty which is known as *Stammering*. This very annoying impediment is occasioned by a want of proper control over the muscles concerned in Articulation; which, instead of obeying the Will, are sometimes affected with an involuntary or spasmodic action, that interrupts the pronunciation of particular words,—just as, in Chorea, the muscles of the limbs are interrupted by spasmodic twitchings, in the performance of any voluntary movement. In fact, persons affected with general Chorea frequently stammer; showing that ordinary Stammering may be considered as a kind of local Chorea. The analogy between the two states is further indicated by the corresponding influence of excited Emotions in aggravating both.—It is in the pronunciation of the consonants of the *explosive* class, that the stammerer usually experiences the greatest difficulty; for the total interruption to the breath which they occasion, is frequently continued involuntarily; so that either the expiration is entirely checked, the whole frame being frequently thrown into the most distressing semi-convulsive movements, or the sound comes out in jerks. Sometimes, however, the spasmodic action occurs in the pronunciation of *vowels* and *continuous* consonants; the stammerer prolonging his expiration, without being able to check it.

984. The best method of curing this defect (where there is no malformation of the organs of speech, but merely a want of power to use them aright), is to study the particular difficulty under which the individual labours; and then to cause him to practise systematically the various movements concerned in the

production of the sounds in question, at first separately, and afterwards in combination,—until he feels that his voluntary control over the muscles is complete. The patient would at first do well to practise sentences from which the explosive consonants are omitted; his chief difficulty, arising from the spasmodic suspension of the expiratory movement, being thus avoided. Having mastered these, he may pass-on to others in which the difficult letters are sparingly introduced; and may finally accustom himself to the use of ordinary language. One of the chief points to be aimed-at, is to make the patient feel that he *has* command over his muscles of articulation; and this is best done, by *gradually* leading him from that which he *can* do, to that which he fears to attempt.

INDEX.


24ColorCard CameraTrax.com
inch 1 2 3